MISCELLANEOUS PAPER EL-80-5

BIOLOGICAL ASSESSMENT OF UPPER MISSISSIPPI RIVER SEDIMENTS

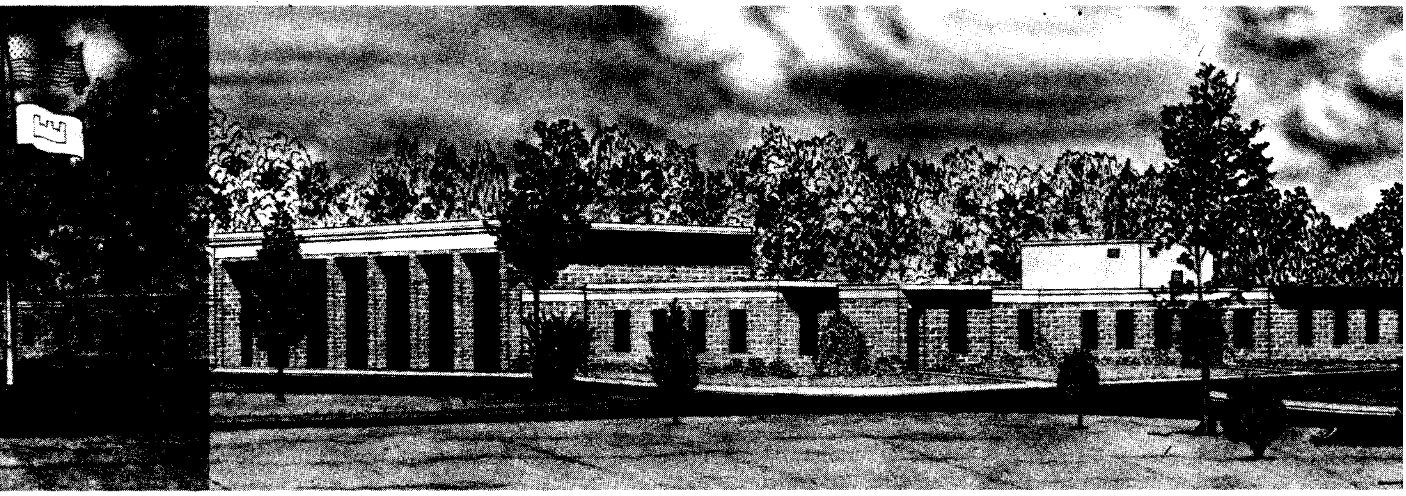
by

Richard Peddicord, Henry Tatem, Alfreda Gibson, Susan Pedron

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

December 1980
Final Report

Approved For Public Release; Distribution Unlimited



Prepared for U. S. Army Engineer District, St. Paul
St. Paul, Minn. 55101
and
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Miscellaneous Paper EL-80-5	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): BIOLOGICAL ASSESSMENT OF UPPER MISSISSIPPI RIVER SEDIMENTS	5. TYPE OF REPORT & PERIOD COVERED: Final report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Richard Peddicord, Henry Tatem, Alfreda Gibson, Susan Pedron	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U. S. Army Engineer Waterways Experiment Station, Environmental Laboratory, P. O. Box 631, Vicksburg, Miss. 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Engineer District, St. Paul, St. Paul, Minn. 55101 and Office, Chief of Engineers, U. S. Army, Washington, D. C. 20314	12. REPORT DATE: December 1980
	13. NUMBER OF PAGES: 82
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bioassay
Biological communities
Dredging
Sediment
Toxicity
Upper Mississippi River

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this study was to determine the potential for polychlorinated biphenyls (PCB) and metals to bioaccumulate in the tissues of fish and invertebrates as a result of exposure to sediment from various dredging sites in the upper Mississippi River area. The acute toxicity of these sediments was of secondary interest.

Water fleas (*Daphnia*), catfish, and bluegills were exposed to suspensions of fine-grained sediment from three test sites and one reference site for

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

4 to 6 days, approximately the duration of a typical dredging and disposal operation on the upper Mississippi River. Survival and tissue concentrations of contaminants in fish were determined after exposure. Fawnfoot and three-ridge clams, mayfly larvae, and amphipods were exposed to deposited sediments for up to 14 days, after which survival and contaminant concentrations in tissues of clams were determined.

All three test sediments were of low toxicity to all species except the amphipods, in that no sediment produced statistically greater mortality than occurred in the controls and reference sediment. Although statistical comparisons were not made, amphipod mortality in some Upper Mississippi River sediments apparently exceeded that in the controls but probably not that in the reference sediment. Bioaccumulation was the exception, rather than the rule, with 72 species-sediment-contaminant combinations being studied and bioaccumulation potential being indicated in 8 (11 percent) of the cases. Even in these cases, resulting concentrations were below those considered likely to cause adverse impacts.

This study provided little indication that typical dredging and disposal operations on the upper Mississippi have a potential to cause ecologically meaningful increases in mortality or bioaccumulation in the species studied.

PREFACE

This report presents the results of a study conducted to examine acute toxicity and bioaccumulation in fish and invertebrates exposed to dredged material and a reference sediment from the upper Mississippi River area. The investigation was supported jointly by the U. S. Army Engineer District, St. Paul, and the Office, Chief of Engineers, U. S. Army, using Dredging Operations Technical Support Program funds for criteria development research administered through the U. S. Army Engineer Waterways Experiment Station (WES).

The work was conducted during the period September 1978-September 1979 by the Environmental Laboratory (EL), WES, Vicksburg, Miss. The study was conducted by Drs. Richard Peddicord and Henry Tatem, Ms. Alfreda Gibson, and Ms. Susan Pedron, Ecosystem Research and Simulation Division (ERSD), EL. The study was under the general supervision of Dr. Robert Engler, Ecological Effects and Regulatory Criteria Group; Dr. Rex Eley, former Chief, ERSD; and Dr. John Harrison, Chief, EL.

The authors would like to express their appreciation to the many people at WES and at the St. Paul District who contributed to the success of this project. Particularly helpful were the personnel of the U. S. Environmental Protection Agency, Environmental Research Laboratory, Duluth, Minn., and especially Drs. John Eaton, John Poldoski, and Leonard Mueller, who provided most of the chemical analyses. The authors would also like to thank Dr. Samuel Fuller of the Academy of Natural Sciences of Philadelphia, who collected and shipped to WES the clams used in the study.

Commanders and Directors of WES during the conduct of the study and preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows: Peddicord, R., et al. 1980. "Biological Assessment of Upper Mississippi River Sediments," Miscellaneous Paper EL-80-5, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

BIOLOGICAL ASSESSMENT OF UPPER MISSISSIPPI RIVER SEDIMENTS

PART I: INTRODUCTION

1. Under Section 404(t) of the Federal Water Pollution Control Act (Public Law 92-500) Amendments of 1977, authority was given to the States to regulate the disposal of dredged material resulting from Federal projects. In this context a stipulation agreement was reached between the Minnesota Pollution Control Agency (MPCA) and the U. S. Army Engineer District, St. Paul, concerning maintenance dredging on the Upper Mississippi River (UMR). This stipulation agreement required the conduct of sediment bioassay/bioaccumulation studies. A meeting of personnel from MPCA, St. Paul District, and the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), was held on 12 July 1978 to discuss the technical format of these studies. The following paragraph is summarized from a Memorandum for Record dated 24 July 1978, describing that meeting, written by the St. Paul District and furnished to MPCA. The fact that MPCA did not respond was taken to indicate concurrence with the contents of the memo.

2. Participants at the 12 July meeting agreed that acute toxicity bioassays were of interest, but that the primary emphasis was to be on potential for bioaccumulation of polychlorinated biphenyls (PCB), mercury (Hg), cadmium (Cd), copper (Cu), and zinc (Zn) (St. Paul District later requested that lead (Pb) be added to this list). The four sediments for study were to be taken from (a) just below the Minneapolis-St. Paul sewage discharges, (b) the head of Lake Pepin, (c) the area below Lake Pepin, and (d) a reference area. The reference sediment was to provide a standard for comparison with results obtained with the three test sediments. The reference, therefore, was to be of a sediment particle size similar to the other sediments and on which a diverse biota was existing at the time of its collection. It was agreed that a Mississippi River backwater area downstream of Lake Pepin would probably be satisfactory for the reference sediment. (St. Paul

District later chose to collect a reference sediment from Lake Polander which they felt met the above conditions and to substitute a Minnesota River sediment for the one to have been taken from an area below Lake Pepin.) It was agreed at the 12 July meeting that solid phase and suspended particulate phase exposures would be conducted. Test species for the solid phase were to be native to the UMR area. Species discussed as possible test organisms included *Hexagenia* sp. nymphs, fingernail clams, and Unionid clams. (St. Paul District later chose mayfly nymphs *Hexagenia limbata*, fawnfoot clams *Truncilla donaciformis*, and three-ridge clams *Amblema plicata* as solid phase test species; EL personnel added the amphipod *Hyallela azteca*.) It was agreed that water fleas *Daphnia* sp. would be used in suspended particulate phase tests, but that the primary interest was in channel catfish *Ictalurus punctatus* and bluegills *Lepomis macrochirus*.

3. In late July 1978, the EL provided St. Paul District with a research proposal to conduct the studies outlined above. This proposal was accepted in a letter of 18 August 1978 from St. Paul District, and initial work began soon thereafter. This report is a description of that research and a discussion of its findings.

PART II: METHODS AND MATERIALS

Animal-Sediment Collection

4. Sediments were collected by St. Paul District personnel on 12-14 September 1978 from four locations in the UMR area using a ponar dredge coated with a noncontaminating paint and fitted with a stainless steel screen. The sediment from each site was placed in polyethylene bags in rigid ice chests and air-shipped to WES. Approximately 120 ℓ of sediment was collected from each of the following locations:

- a. Lake Pepin - Mississippi River Mile 784.2.
- b. Mississippi River - River Mile 821.1.
- c. Minnesota River - River Mile 14.3-14.7.
- d. Lake Polander - Mississippi River - Winona Dam. This was selected by St. Paul District as the reference sediment.

5. The Lake Polander sediment was provided to the EL as a reference sediment having all the characteristics discussed at the 12 July 1978 meeting with MPCA and St. Paul District personnel. It was regarded as a sediment having characteristics such as low toxicity and contaminant bioavailability which made it capable of supporting a diverse fauna and resulted in its being considered generally environmentally acceptable in the field. The response of the test species to Lake Polander sediment under the experimental conditions was thus considered to be the best laboratory simulation possible of biological responses to a sediment known to possess generally acceptable characteristics. Therefore, responses to other sediments were evaluated in comparison to responses to the Lake Polander reference sediment. Other sediments producing less mortality or bioaccumulation than the reference sediment were regarded as unlikely to be less acceptable in the field than the Lake Polander sediment in terms of the species and parameter in question. Test sediments producing higher mortality or bioaccumulation than the reference sediment were regarded as potentially less acceptable in terms of that particular parameter and species than the Lake Polander sediment.

6. Sediment samples were received on 15 September 1978. Excess water was removed from the bags and they were placed in a cold room at $4^{o}C$ until used in the experiments. Prior to initiation of experiments the bags of sediment from each collection site were thoroughly mixed with a polyethelene spatula. Three 1-ℓ samples of each sediment were placed in glass jars with aluminum foil cap liners for PCB analysis. Three 1-ℓ samples were also preserved in polyethylene jars for bulk or total sediment anaysis. All sediment samples were stored at $4^{o}C$ until analyzed. In two of the acute toxicity bioassays, a Vicksburg area sediment, referred to as VC sediment, known to be toxic to a variety of organisms, was included for comparison.

7. Animals were obtained from a variety of sources. Two species of fish, channel catfish *(Ictalurus punctatus)*, approximately 8 cm in length, and bluegill *(Lepomis macrochirus)*, approximately 4 cm in length, were obtained from the U. S. Fish and Wildlife Service National Fish Hatchery in Natchitoches, Louisiana. They were held in separate tanks in approximately 400 ℓ of water at $20 \pm 2^{o}C$ in a temperature-controlled greenhouse. The tanks received an intermittent flow of tap water that had been aged for 14 to 30 days, sterilized by ultraviolet light, and passed through a particle filter. Catfish were treated daily for an external infection with a single dose of formalin at a concentration of about 10 ppm. This infection was eradicated and treatments were ended 5 days before exposure to the sediments began. Both species of fish were held in the laboratory approximately 3 weeks before testing began. During that time they were fed Tetramin daily until intensity of feeding activity began to diminish. Feeding was discontinued the day before tests began and the fish were not fed during the testing period.

8. Three-ridge clams *Amblema plicata* and fawnfoot clams *Truncilla donaciformis* were taken from UMR backwater areas, placed in damp burlap bags in boxes, and shipped by air to WES. Animals were received at WES and placed in aerated aged tap water at $17^{o}C$ less than 24 hr after their collection. The three-ridge clams survived well, but the fawnfoot clams suffered considerable mortality during shipping and handling.

Mortalities ceased after the first few days in the laboratory, and survivors exhibited normal pumping and burrowing activity during the 2 weeks prior to exposure. Clams were held in the laboratory approximately 3 weeks before testing began.

9. Mayfly nymphs *Hexagenia limbata* were collected by Dennis Anderson of the St. Paul District and were placed in small styrofoam containers with some aquatic plants for air shipment to WES. Many of the animals died during shipping or shortly after arrival. Survivors were held in aged tap water at 16^{o} to $18^{o}C$ in shallow pans containing clean natural sediment and aquatic plant material. Although few of the surviving *Hexagenia* burrowed into the sediment layer, they were active and appeared to be in good condition.

10. *Daphnia magna*, a small water column crustacean known as the water flea, was from a long-standing laboratory culture originally obtained from Carolina Biological Supply Co. These organisms had been maintained in laboratory culture at room temperature in open trays following procedures described by the American Public Health Association (1975).

11. Freshwater amphipods *Hyalella azetca* were collected from a small stream draining Brown's Lake at the WES. These animals were held in open polyethylene trays in aged tap water with a mass of aquatic vegetation from the collection site. Temperature was maintained at 21^{o} to $23^{o}C$.

Acute Toxicity Bioassays

12. The limited number of mayfly larvae *H. limbata* available for testing was used in one small-scale bioassay with test sediments from the Minnesota River and Lake Pepin, and the Lake Polander reference sediment. Three crystallizing dishes containing 300 ml of sediment and 1200 ml of aged tap water were placed in a water bath. Temperature was maintained at $19^{o}C$ to approximate typical UMR summer temperature. Ten *Hexagenia* were placed in a bowl of each sediment. Aeration was provided

to the test dishes. The number of suvivors in each dish was determined after 7 and 11 days of exposure.

13. The survival of freshwater amphipods *H. azteca* in all four of the UMR sediments was determined. Test containers were crystallizing dishes placed in a water bath to control temperature at $19^{\circ}C$. Two replicates of 1200 ml aged tap water over 300 ml of sediment were established using each of the three UMR test sediments and the Lake Polander reference sediment. In addition, two replicates of a culture water control without sediment were established, as were two replicates of the VC sediment from the Vicksburg area known to be toxic to a variety of organisms. All test containers were aerated. Twenty individual *H. azteca* were placed in each test container and survival was determined after 10 days exposure.

14. Two acute toxicity experiments with water fleas *Daphnia magna* were conducted, both involving exposure to suspended particulate phase (SPP) of each of the four UMR sediments. The SPP, which is muddy water obtained from an unfiltered elutriate, was prepared by slight modification of previously described methods (Shuba, Tatem, and Carroll 1978; Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material 1978). Aged tap water and sediment were mixed in a 4:1 ratio in a glass container. This mixture was shaken or stirred vigorously by hand for 5 min. The container was then placed on a shaking platform and rotated for 30 min at approximately 110 rpm, after which the mixture was allowed to settle overnight in a cold room. The supernatant was then siphoned off and centrifuged at 3200 rpm for 10 to 40 min, depending on the amount of silt and clay present, to produce a suspension of particles through which it was possible to observe and count the *Daphnia* during the toxicity test. This removed sufficient particles to minimize physical effects on the *Daphnia* and allow determination of chemical toxicity, which was of primary interest. Thus, the laboratory exposures represented conditions a few hundred meters downstream of a discharge pipe rather than the highly turbid conditions immediately adjacent to the pipe. Animals were exposed to either 100 percent SPP or 50 percent SPP in aged tap water in

acid-rinsed glass petri dishes or finger bowls. Control animals were exposed to a mixture of equal parts culture water and aged tap water under the same conditions as the test animals. The containers, which were not aerated, were maintained under a 12-hr light and 12-hr dark photoperiod and a temperature of $20^{\circ}C \pm 1^{\circ}C$ in a water bath. In both experiments, survivors were counted periodically over a light box without disrupting the experimental exposures. The first *D. magna* experiment involved four replicates of 100 and 50 percent SPP of each of the three UMR test sediments, SPP of Lake Polander reference sediment, and a control. Each replicate consisted of 10 adult organisms in 1 ℓ of test or control water. Live *D. magna* were counted in each container after 16, 40, and 96 hr of exposure. The second experiment employed six 100-ml replicates of the control and 100 percent SPP of each of the four UMR sediments, but did not use 50 percent SPP. Six replicates of SPP of the VC sediment were included, as were six replicates of a second control. The test was initiated with five first instar *D. magna* per replicate. Survivors were counted after 18, 42, 96, and 144 hr of exposure.

Fish Bioaccumulation Potential

15. The bioaccumulation potential experiments with fish were designed to approximate worst-case exposure to suspended sediment concentrations that might be encountered by fish due to a typical UMR area dredging and disposal operation. Exposures were carried out in 84-ℓ cylindrical fiberglass tanks with hemispherical bottoms. The aquarium system, described in detail in Peddicord and McFarland (1978), was designed to maintain constant concentrations of particulates in suspension. Six replicate suspensions of each sediment were randomly positioned within the 24-aquarium system. Due to equipment failure, only five replicates of the Mississippi River sediment were obtained. Exposures were run for 6 days at $18^{\circ}C$.

16. Because sand does not remain in suspension downstream from dredges, the sand fraction of the sediments was removed prior to preparing the suspensions. This was done by mixing a slurry of sediment in

aged tap water in 1-ℓ glass cylinders, allowing the sand to settle for 30 sec, and decanting off the sediment remaining in suspension. This suspension was then passed through a 200-mesh stainless steel screen to remove any remaining sand and the resulting stock suspensions of the four test sediments were stored at $4^{\circ}C$ until used in the experiments. The particle concentration in the stock suspension of each sediment was determined by filtering a known volume through a 0.45-μ filter and determining the dry weight of the residue. An appropriate volume of each stock suspension was placed in the respective aquaria, which were filled with aged tap water to provide a final volume of 84 ℓ of test suspension with a suspended particulate concentration of 300 mg/ℓ. Every other day 20 ℓ of suspension was removed from each aquarium and correct volumes of the appropriate stock suspension and aged tap water were added to restore the original volume and suspended sediment concentration in the aquaria.

17. To begin the experiments, 18 catfish and 17 bluegills were netted from the holding tanks and randomly assigned to each aquarium. The fish were of such a size that predation was not a problem.

18. At the end of the 6-day exposure period, the fish were removed from the aquaria, mortalities were noted, and survivors were prepared for tissue analysis. Since the purpose was to determine the potential for accumulation of contaminants in the tissues, it was necessary to remove sediment from the body surfaces and digestive tracks before analysis. To have not done so would have included the contaminants associated with that sediment in the analyses, giving a misleading estimate of tissue bioaccumulation (Peddicord and McFarland 1978; Flegal and Martin 1977; Bertine and Golberg 1972). The fish body surfaces were rinsed in distilled water. The catfish digestive tracks were excised and bluegill digestive tracks were flushed of sediment by the method of Baker and Fraser (1976). All surviving fish of each species from each aquarium were divided into two samples for analysis. Samples for PCB analysis were frozen in glass vials with aluminum foil cap liners. Samples for metals analysis were frozen in clear polyethylene wrap in freezer bags. In addition to sediment-exposed fish from the

aquaria, six replicate samples of each species were preserved from the holding tanks on the day the experiment started in order to determine background levels. Six replicate samples of catfish from the holding tanks were also obtained on day 6 when the exposure ended. Fish in background samples were prepared and preserved in the same manner as the exposed fish.

19. Water samples were taken from the aquaria for chemical analyses at the end of the 6-day exposure. One litre of water from each aquarium was passed through a 0.45-μ filter and prepared for analysis of materials in solution. Samples for metals analysis were preserved with 3 ml concentrated nitric acid in polyethylene bottles, and PCB samples were placed in glass bottles with aluminum foil cap liners and no preservative. In addition, 1 ℓ of unfiltered muddy water was taken from each aquarium for whole water analysis. Metals samples were placed in polyethylene bottles, and PCB samples were stored in glass bottles with aluminum foil cap liners. No preservatives were added to whole water samples, which were shaken to resuspend all sediment particles before analysis. All water samples were stored at $4^{\circ}C$ until analyzed.

Clam Bioaccumulation Potential

20. Clams were exposed to the sediments in 18.9-ℓ glass aquaria placed in a water bath for temperature control. Twenty-four aquaria were prepared containing 1 ℓ of clean sand and 13.5 ℓ of aged tap water. Six replicates of each of the four UMR sediments were prepared by removing a portion of the water from each aquarium in a large flask to which 1.5 ℓ of the appropriate test sediment was added. The contents were shaken by hand and the resulting slurry was poured into the appropriate aquarium and spread evenly over the layer of sand. Temperature in the aquaria was controlled at $20^{\circ}C \pm 1^{\circ}C$. Aeration was provided to the water column and pH and dissolved oxygen (DO) levels were determined to be at acceptable levels before introduction of the clams. Twenty fawnfoot clams and 18 three-ridge clams were placed in the newly

deposited test sediment in each aquarium. Ten litres of water was replaced in each aquarium daily, being careful not to resuspend the sediment.

21. One half of the clams were taken for tissue analyses after 7 days of exposure and the remainder after 14 days, at which time any mortalities were noted. Animals to be analyzed for contaminant uptake were removed from the sediment and placed in flowing sediment-free aged tap water for 36 hr to allow them to void the guts and gills of sediment before the tissues were preserved for analysis. Background tissue samples were obtained on day 0 when the test was initiated from animals that had been in the holding tanks. These animals were also placed in flowing water for 36 hr before being preserved for analysis. After the purging period in clean water, the tissues of all clams of each species in each aquarium were removed from the shells and composited to make one sample. Samples for metals analyses were frozen in clear polyethylene wrap in freezer bags, and samples for PCB analysis were frozen in glass vials with aluminum foil cap liners.

22. Unfiltered whole water samples were taken from each aquarium on day 6 for chemical analyses. Samples for PCB analyses were placed without preservative in glass jars with aluminum foil cap liners. Metals samples were preserved with 3 ml concentrated nitric acid per litre in polyethylene bottles. Water samples were stored at $4^{o}C$ and were thoroughly shaken to resuspend any sediment particles before being analyzed.

Chemical and Physical Analyses

23. All tissue and water analyses and the sediment analyses for PCB, Hg, Cu, Pb, and Zn were performed by the U. S. Environmental Protection Agency's (EPA) Environmental Research Laboratory, Duluth, Minnesota. All tissue, water, and sediment samples were packed in ice and shipped by air to the Duluth laboratory where sediment and water samples were held at $4^{o}C$ and tissue samples were placed in a freezer

until analyzed. All other analyses were performed by the EL Analytical Laboratory Group, WES.

24. Mercury analyses in the sediment, water, and tissue samples were performed by the EPA Duluth lab according to the methods described by Olson et al. (1975). All fish data were obtained by analysis of a homogenate of two to four whole fish per sample. The entire mass of clam tissue in each sample was homogenized for analysis. Eight randomly selected samples of each species had 0.1 μg of $HgCl_2$ added, and recovery of these spikes averaged 94 percent. Tissue and sediment data were expressed as total mercury concentration in micrograms per gram (μg/g), which is parts per million (ppm), on a wet weight basis, or as micrograms per litre (μg/ℓ), which is parts per billion (ppb), in water samples.

25. The other metals in sediment, water, and tissues were analyzed by EPA using the methods of Poldoski and Glass (1975) and EPA (1974, 1977). All analyses were performed by atomic absorption spectrometry using flame or graphite furnace atomization. Quality control measures included the running of blanks, spiked samples, and standard reference samples and the use of background correction. In addition, some homogenized samples were split and each portion analyzed separately, providing an indication of analytical variability. Data are presented as sediment or whole body metals concentration in μg/g (ppm) dry weight or as μg/ℓ (ppb) in water samples. Metals analyses were not performed on all samples due to insufficient material remaining after an aliquot was removed for Hg analysis.

26. Analyses for PCB in sediment, water, and tissues were performed by EPA following the methods of Thompson (1977) and Department of Health, Education, and Welfare, Food and Drug Administration (FDA) (1975) on a Hewlett Packard automatic gas chromatograph. A glassware blank and a spike of 0.1 μg/ml PCB were run with each set of eight tissue samples. All tissue values are based on the analysis of a homogenate of several organisms. Total PCB concentrations were determined on all samples, as well as Arochlor 1016 and 1254 on all sediment and

tissue samples. Data are presented in μg/g (ppm) wet weight for sediment and whole body concentrations and in μg/ℓ (ppb) for water samples.

27. Particle-size distributions of the four test sediments were determined by EL using the hydrometer method described by Patrick (1958). Hydrometer readings were made in three replicates of each sediment and average readings were used to calculate percent sand, silt, and clay of each sediment.

Statistical Analyses

28. All statistical analyses were performed using the Statistical Analyses System (SAS) at the 0.05 significance level. Duncan's multiple range test was used for all mean contrasts to determine which data averages differed significantly from each other at the 0.05 significance level. In statistical analyses of the bioaccumulation data, values for split samples were averaged and treated as the datum for that sample. In cases where chemical concentrations were less than detection limits, the data were incorporated in statistical analyses by treating the detection limits as if they were the data.

29. Mortality in *Daphnia* and bioaccumulation in the fish, which comprise the water-column organisms in the study, were evaluated by comparing responses of organisms exposed to sediment suspensions to responses of organisms in clear water. The control organisms in the *Daphnia* bioassays experienced exactly the same conditions, except for sediment, as the test organisms and were included as a treatment in the statistical analyses. The background data in the fish bioaccumulation potential studies were from animals from the holding tanks, which received slightly different physical treatment from the test organisms and were sampled at the beginning of the test. These background tissue data were incorporated in the statistical analyses since they provide information on the tissue concentrations present in the fish prior to any exposure to suspensions of any of the sediments. Bioaccumulation potential in the benthic clams was evaluated by comparing data from organisms exposed to the test sediments to data from those exposed to

the reference sediment, which was considered to possess generally acceptable environmental characteristics.

PART III: RESULTS AND DISCUSSION

Sediment Characterization

30. Results of the particle-size analyses are presented in Appendix A, Table A1. The Minnesota River sediment was the coarsest material tested, having the highest percentage of sand and the lowest percentages of both silt and clay. The Mississippi River sediment was only slightly less coarse while the two lake sediments were substantially finer in texture. The Lake Polander sediment, which served as a reference, was considerably finer grained than the others, with over 80 percent silt and clay.

31. Bulk or total concentrations of chemical constituents in the four UMR sediments are presented in Table A2. Analyses of variance comparing concentrations of total PCB, Hg, Pb, Cu, and Zn in the four UMR sediments are presented in Table 1. No statistical difference at the 0.05 significance level was found between Pb concentrations in the four sediments, while differences significant at the 0.01 significance level were found for total PCB, Hg, Cu, and Zn. Mean contrasts for these parameters to determine which sediments differed significantly are also presented in Table 1. The Mississippi River and Lake Pepin sediments were statistically higher in bulk content of all four parameters than the Minnesota River sediment and the Lake Polander reference sediment. Although no statistical comparisons could be made, the Mississippi River and Lake Pepin sediments were also higher in total Cd, Cr, and NH_3-N than the Lake Polander reference sediment and the Minnesota River sediment (Table A2). The relatively low concentrations of chemical constituents in the Lake Polander sediment indicate the appropriateness of its selection as the reference sediment. The Minnesota River sediment, in addition to containing statistically lesser amounts of total PCB, Hg, Cu, and Zn, was also lowest in total Cd, Cr, Mn, and Ni. However, it was the highest of the four UMR sediments in total oil and grease. The concentration of even this parameter was low in comparison with contaminated sediments from other regions (Di Salvo et al. 1977). The low

Table 1

Comparison of Bulk or Total Contaminant Concentrations in Sediment from Four UMR Locations

Parameter	Analyses of Variance: Source	DF	Sum of Squares	Mean Square	F	Significance†	Mean Contrasts: Location	Mean††
								(PCB, µg/g wet wt)
Total PCB	Location	3	0.01288	0.00429	72.49	**	Mississippi River	0.090
	Error	8	0.00047	0.00006			Lake Pepin	0.065
	Total	11	0.01336				Lake Polander (reference)	0.022
							Minnesota River	0.009
								(Hg, µg/g wet wt)
Hg	Location	3	0.01218	0.00406	37.01	**	Mississippi River	0.118
	Error	8	0.00088	0.00011			Lake Pepin	0.077
	Total	11	0.01306				Lake Polander (reference)	0.055
							Minnesota River	0.031
Pb	Location	3	9,422.41667	3140.80556	3.05	n.s.		
	Error	8	8,248.00000	1031.00000				
	Total	11	17,670.41667					
								(Cu, µg/g dry wt)
Cu	Location	3	320.48836	106.82945	31.15	**	Mississippi River	25.3
	Error	8	27.43873	3.42984			Lake Pepin	23.5
	Total	11	347.92709				Lake Polander (reference)	18.4
							Minnesota River	12.0
								(Zn, µg/g dry wt)
Zn	Location	3	6,700.71333	2233.57111	60.30	**	Mississippi River	93.4
	Error	8	296.33833	37.04229			Lake Pepin	88.8
	Total	11	6,997.05167				Lake Polander (reference)	70.2
							Minnesota River	33.4

† Entries in this column are defined as follows:
  ** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.
  n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

†† Means connected by the same vertical line are not different at the 0.05 significance level. Means not connected by the same line are different at the 0.05 significance level.

concentrations of most chemical constituents in the Minnesota River sediment are probably related to the fact that it was the sandiest sediment tested and thus had the least capacity to sorb and hold contaminants.

Water Chemistry

32. Concentrations of most chemical constituents were below detection limits in most unfiltered water samples from the clam exposure aquaria (Table A3). No PCB, Cd, or Cr was measured in the water overlying any of the four sediments, while Cu, Pb, and Hg were detected in only one replicate from one sediment condition. Zinc was detected at low levels in one replicate sample of water overlying sediment from three of the four locations. Water overlying the Lake Polander reference sediment did not contain measurable levels of any contaminant analyzed, again indicating it to be an appropriate reference sediment.

33. Analyses of unfiltered samples from the aquaria in which fish were exposed to suspensions of UMR sediment are presented in Table A4. Total PCB concentrations were less than the detection limit of 0.05 μg/ℓ (ppb) in all samples of all test and reference sediment suspensions. Mercury analyses did not indicate concentrations above the detection limit of 0.5 μg/ℓ (ppb) in any sample. Since the samples were stored in sealed bottles just above freezing but were not acidified, it is possible that some Hg may have been lost to volatilization prior to analysis. This is considered highly unlikely to have been a major loss since the sulfur content of all sediments was high enough that any potentially free Hg was probably bound up as mercuric sulfide, which is nonvolatile. Thus, although quantitative data are not available, it is likely that total Hg concentrations in the suspensions were really less than 0.5 μg/ℓ. Suspensions of all UMR test sediments and the reference sediment contained measurable concentrations of Cd, Cu, Cr, Pb, and Zn (Table A4). Analyses of variance comparing concentrations of each of these parameters among the four sediments are shown in Table 2. There were no statistical differences in Cu or Zn concentrations in suspensions

Table 2

Comparison of Concentrations of Chemical Constituents in

Unfiltered Water from the Fish Experiment

Parameter	Analyses of Variance						Mean Contrasts	
	Source	DF	Sum of Squares	Mean Square	F	Significance†	Location	Mean, μg/ℓ (ppb)††
Cd	Location	3	0.83838	0.27946	34.33	**	Mississippi River	0.6
	Error	19	0.15467	0.00814			Lake Pepin	0.4
	Total	22	0.99304				Minnesota River	0.2
							Lake Polander (reference)	0.1
Cu	Location	3	273.96667	91.32222	0.43	n.s.		
	Error	19	4018.03333	211.47544				
	Total	22	4292.00000					
Cr	Location	3	49.15652	16.38551	4.00	*	Lake Pepin	6
	Error	19	77.80000	4.09474			Mississippi River	4
	Total	22	126.95652				Lake Polander (reference)	4
							Minnesota River	3
Pb	Location	3	53.77826	17.92609	7.45	**	Mississippi River	9
	Error	19	45.70000	2.40526			Lake Pepin	9
	Total	22	99.47826				Minnesota River	7
							Lake Polander (reference)	6
Zn	Location	3	1153.85072	384.61691	2.15	n.s.		
	Error	19	3395.36667	178.70351				
	Total	22	4549.21739					

† Entries in this column are defined as follows:
** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.
n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.
* Statistical difference at the 0.05 significance level. Mean contrasts are shown for this parameter.

†† Means connected by the same vertical line are not different at the 0.05 significance level. Means not connected by the same line are different at the 0.05 significance level.

of any of the four UMR sediments. Mean contrasts for those parameters showing statistical differences among the locations are also presented in Table 2. These showed that, although differences were numerically small, suspensions of Mississippi River and Lake Pepin sediments had statistically higher concentrations of Pb and Cd than suspensions of Minnesota River sediment and the Lake Polander reference sediment. The low levels of these metals again support the selection of Lake Polander sediment as the reference sediment. Concentrations of Cr in suspensions of Lake Pepin sediment were statistically higher than in suspensions of Minnesota River sediment. None of the suspensions of UMR sediments differed significantly from the Lake Polander reference sediment in Cr content.

34. Table A5 provides the data on chemical constituents in filtered water samples taken from the fish exposure aquaria at the same time as the unfiltered samples just discussed. Concentrations of PCB, Cd, Cr, and Pb were below detection limits in all samples. The filtrate of suspensions of Lake Pepin sediment contained measurable amounts of Cu, Hg, and Zn. Water from suspensions of Minnesota River sediment contained Cu in one sample and Zn in all samples. Only Zn was measurable in the filtrate of suspensions of Mississippi River sediment and the Lake Polander reference sediment. An analysis of variance showed no statistical differences in dissolved Zn concentration in filtrates of suspensions of the three UMR test sediments and the reference sediment (Table 3). Comparison of the Zn data in unfiltered water samples from the fish exposure aquaria (Table A4) with those in filtered samples (Table A5) showed that between 40 and 61 percent of the Zn present in the unfiltered samples was associated with the suspended sediment particles rather than in solution.

Species Survival

Amphipod - *Hyalella azteca*

35. Survival of the freshwater amphipod *H. azteca* in the culture water controls was complete (Table A6). After 10 days exposure,

Table 3

Analysis of Variance Table Comparing Zinc Concentration in Filtered Water Samples from Aquaria in Which Fish Were Exposed to Suspensions of Four UMR Sediments for 6 Days

Parameter	Source	DF	Sum of Squares	Mean Square	F	Significance†
Zn	Location	3	211.85072	70.61691	1.87	n.s.
	Error	19	719.36667	37.86140		
	Total	22	931.21739			

† n.s. indicates no statistical difference at the 0.05 significance level.

the least mortality occurred among animals exposed to Minnesota River sediment. Mortality was progressively higher in Lake Pepin sediment and the Lake Polander reference sediment, and the greatest mortality among the UMR sediments occurred in the Mississippi River sediment. This mortality was not nearly as severe as in the VC sediment, known from previous work to be highly toxic, where no organisms survived 10 days exposure (Table A6). Preliminary statistical analysis showed that the assumption of homogeneity of variances underlying the analysis of variance could not be satisfied, probably due in part to the great difference between replicates in amphipods exposed to the Lake Pepin sediment. For this reason statistical comparisons were not made. However, there appear to be differences in toxicity to *H. azteca* between the UMR sediments and the controls, although it is questionable whether mortality in any UMR sediment exceeded that in the reference sediment.

Mayfly - *Hexagenia limbata*

36. The survival of larval mayflies *H. limbata* exposed to UMR sediments is presented in Table A7. The greatest survival was in the Lake Polander reference sediment, while least survival was in the Minnesota River sediment. The small number of animals available for testing precluded the use of replicates for statistical analysis of the data. However, it should be noted that live *Hexagenia* were found in the Lake Pepin and Lake Polander sediments when they arrived in the laboratory. This tends to confirm the Lake Polander sediment as an appropriate reference. The good survival in the reference sediment confirms the acceptability of the testing procedure. The survival of *Hexagenia* in the UMR sediments (Table A7) is inversely correlated with increasing grain size of the sediments (Table A1). Therefore, it is entirely possible that the mortality in the Minnesota River sediments may simply reflect physical incompatibility of this species with coarse-textured sediment, rather than toxicity. This idea is supported by the fact that the Minnesota River sediment caused the least mortality to every other species tested.

Water flea - *Daphnia magna*

37. The survival of *D. magna* in Experiment 1 is shown in Table A8.

The only organism that died after 16 hr exposure was in 100 percent SPP of the Lake Polander reference sediment. After 40 hr of exposure, survival in both 50 and 100 percent SPP of the Lake Polander reference sediment was less than in the control, while survival in 100 percent SPP of the other UMR sediments exceeded that in the control. The relationships were generally similar after 96 hr of exposure, with control mortalities exceeded only by those in both concentrations of SPP of the Lake Polander reference sediment and in 100 percent Mississippi River SPP (Table A8).

38. A factorial analysis of variance (ANOVA) (Table 4) showed that SPP concentration did not statistically influence survival, but that location and exposure time did and that these two factors interacted to produce statistically different mortality patterns over time in the various sediments. A mean contrast, based on a one-way analysis of variance of the combined concentration data for each location and time, describes this interaction (Table 4). Survival in the control after a 40-hr exposure statistically exceeded survival in SPP of the Lake Polander reference sediment, but was statistically less than in SPP of any other sediment after a 40-hr exposure. There was no statistically significant decrease in survival in SPP of Minnesota River and Lake Pepin sediments throughout the 96-hr exposure period. Survival in these two sediments was statistically higher than in the control after 96 hr, while survival in SPP of Mississippi River and the Lake Polander reference sediments was not statistically different from the control. Survival in all three UMR test sediments was statistically not different from, or higher than, survival in both the control and the Lake Polander reference sediment after 96 hr.

39. The adult *D. magna* with which Experiment 1 was initiated reproduced during the exposure period. Since the experiment was not designed to quantify reproductive responses, it is not possible to determine whether equal numbers of offspring were produced in all treatments or whether all offspring produced remained alive at the 96-hr observation period. Therefore, it is not possible to compare reproductive responses in this experiment. However, some offspring were

Table 4

Comparison of Survival of Adult Water Flea *Daphnia magna* Exposed to Suspended Particulate Phase (SPP) of Four UMR Sediments in Experiment 1

Source	DF	Sum of Squares	Mean Square	F	Significance†	Location	Time	Mean Survival
	Analyses of Variance					Mean Contrast		
				Factorial ANOVA				
Location	4	103.65741	25.90907	15.18	**			
Concentration	1	0.04167	0.03414	0.02	n.s.			
Time	3	182.74074	91.36447	53.53	**			
Location × concentration	2	3.70833	1.22889	0.72	n.s.			
Location × time	8	61.34259	7.66349	4.49	**			
Concentration × time	2	0.27083	0.13654	0.08	n.s.			
Location × concentration × time	6	4.97917	0.83633	0.49	n.s.			
Error	81	138.25000	1.70679					
Total	107	494.99074						

(Continued)

† Entries in this column are defined as follows:

** Statistical difference at the 0.01 significance level.
n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

Table 4 (Concluded)

Analyses of Variance						Mean Contrast		
Source	DF	Sum of Squares	Mean Square	F	Significance†	Location	Time	Mean Survival††
One-Way ANOVA-Location Data at Each Time								
Location - time	14	347.74074	24.83862	15.69	**	Control	16	10.0
Error	93	147.25000	1.58333			Minnesota River	16	10.0
Total	107	494.99074				Mississippi River	16	10.0
						Lake Pepin	16	10.0
						Lake Pepin	40	9.9
						Lake Polander (reference)	16	9.9
						Minnesota River	40	9.5
						Mississippi River	40	9.3
						Control	40	9.0
						Minnesota River	96	8.6
						Lake Pepin	96	8.3
						Control	96	6.3
						Mississippi River	96	6.0
						Lake Polander (reference)	40	6.0
						Lake Polander (reference)	96	4.6

† Entries in this column are defined as follows:
** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.
†† Means connected by the same vertical line are not different at the 0.05 significance level. Means connected by the same line are different at the 0.05 significance level.

produced in both SPP concentrations of all sediments (Table A9). Larval *Daphnia* are widely regarded as very sensitive to most toxicants and the ability to support *Daphnia* reproduction is considered evidence of good quality laboratory water (American Public Health Association 1975).

40. The survival data from *D. magna* Experiment 2 are presented in Table A10. Some mortality had occurred in all treatments, including the controls, by 18 hr of exposure. A factorial analysis of variance (Table 5) showed that both location and exposure time had statistically significant effects on survival, but that their interaction was not significant. In other words, the patterns of mortality over time were not statistically different in SPP of the three test sediments, SPP of the reference sediment, and the controls. One-way analysis of variance comparing survival in SPP of different sediments at both 96 and 144 hr showed statistical differences between locations at both times (Table 5). Mean contrasts showed that after 96 hr exposure, survival was not statistically different from either control in the SPP of the Minnesota River, Mississippi River, or Lake Pepin sediments (Table 5). There were no statistical differences among survival in the Lake Polander reference sediment, control A, and the Mississippi River and Lake Pepin sediments. Survival in SPP of Minnesota and Mississippi River and Lake Pepin sediments was not statistically different from either control. Survival in Lake Polander SPP was significantly less than in Control B but not Control A. After 144 hr of exposure, the relative toxicities of the sediments and their statistical relationships were identical (Table 5). It is possible that the patterns of mortality over time were different for the various locations in Experiment 1 but not in Experiment 2 due to the fact that *D. magna* of mixed ages were used in Experiment 1 while Experiment 2 utilized only first instar individuals.

Bioaccumulation Potential

Fawnfoot clam - *Truncilla donaciformis*

41. The survival of fawnfoot clams exposed to deposited UMR sediments for 14 days is shown in Table A11. One clam died in Lake

Table 5

Comparison of Survival of First Instar Water Flea *Daphnia magna* Exposed to Suspended Particulate Phase (SPP) of Four UMR Sediments in Experiment 2

Analyses of Variance						Mean Contrast	
Source	DF	Sum of Squares	Mean Square	F	Significance†	Location	Mean Survival††
		Factorial ANOVA					
Location	6	174.29167	29.04706	25.03	**		
Time	3	73.17956	24.39350	21.02	**		
Location × time	17	8.97321	0.52222	0.45	n.s.		
Error	135	156.6667	1.16049				
Total	161	413.11111					
		One-Way ANOVA - 96 hr				96 hr	
Location	6	41.95238	6.99206	4.93	**	Control B	3.2
Error	35	49.66667	1.41905			Minnesota River	3.2
Total	41	91.61905				Mississippi River	2.8
						Control A	2.5
						Lake Pepin	2.3
						Lake Polander (reference)	1.5
						VC sediment	0.2

(Continued)

† Entries in this column are defined as follows:

** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.

n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean was unnecessary.

†† Means connected by the same vertical line are not different at the 0.05 significance level. Means not connected by the same line are different at the 0.05 significance level.

Table 5 (Concluded)

Analyses of Variance						Mean Contrast	
Source	DF	Sum of Squares	Mean Square	F	Significance†	Location	Mean Survival
		One-Way ANOVA - 144 hr				144 hr	
Location	5	37.22222	7.44444	4.82	**	Minnesota River	3.0
Error	30	46.33333	1.54444			Mississippi River	2.8
Total	35	83.55555				Control A	2.3
						Lake Pepin	1.8
						Lake Polander (reference)	1.3
						VC sediment	0.0

† Entries in this column are defined as follows:

** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.

Polander sediment and two clams died in Mississippi River sediment. No other deaths occurred during the 14-day exposure period.

42. Contaminant concentrations in tissues of fawnfoot clams after 7 and 14 days of exposure to UMR sediments are presented in Table A12. After an adequate mass of tissue was allocated for PCB analysis, sufficient tissue for metals analysis was not available for all samples. Mercury concentrations were below the detection limit of 0.05 μg/g wet tissue weight in all samples in which there was sufficient tissue available for analysis. Analyses for Cd, Pb, Cu, and Zn were performed on clams exposed 7 days to Mississippi and Minnesota River sediments and the Lake Polander reference sediment. Since no metals data were available for fawnfoot clams exposed to Lake Pepin sediment, statistical comparisons were performed among only three sediments. There were no statistically significant differences in Pb, Cu, or Zn concentrations among clams exposed to the three UMR sediments (Table 6). That is, neither of the test sediments caused tissue concentrations of these metals to be raised above the levels in clams in the reference sediment. There was a statistically significant difference in concentrations of Cd in clams exposed to the three sediments (Table 6). A mean contrast (Table 6) showed that neither test sediment produced Cd concentrations statistically higher than those produced by the Lake Polander reference sediment. Indeed, Cd in clams exposed to Mississippi River sediment was statistically lower than in the reference. The Mississippi River sediment, which had the highest total Cd concentration (Table A2), produced the lowest tissue Cd concentration, while the Minnesota River sediment, which had the lowest total Cd concentration, resulted in the highest concentration in the tissues.

43. Results of a factorial analysis of variance comparing total PCB concentration in tissues of fawnfoot clams exposed to all four UMR sediments for 7 and 14 days are presented in Table 7. This indicated that the location from which the sediment sample was taken had no statistically significant influence on clam PCB concentration. Exposure time did have a statistically significant influence on tissue concentration. However, the interaction of time and location was not significant,

Table 6

Comparison of Contaminant Concentrations in Tissue of Fawnfoot Clam *Truncilla donaciformis* Exposed to Three UMR Sediments for 7 Days

	Analyses of Variance						Mean Contrasts	
Parameter	Source	DF	Sum of Squares	Mean Square	F	Significance†	Location	Mean Cd, μg/g dry wt††
Cd	Location	2	0.77349	0.38674	6.67	*	Minnesota River	1.612
	Error	9	0.52202	0.05800			Lake Polander (reference)	1.421
	Total	11	1.29551				Mississippi River	0.951
Pb	Location	2	0.01843	0.00921	0.10	n.s.		
	Error	9	0.80841	0.08982				
	Total	11	0.82684					
Cu	Location	2	0.92951	0.46476	0.44	n.s.		
	Error	9	9.42349	1.04705				
	Total	11	10.35300					
Zn	Location	2	3,797.25000	1898.62500	2.06	n.s.		
	Error	9	8,293.66667	921.51852				
	Total	11	12,090.91667					

† Entries in this column are defined as follows:
  * Statistical difference at the 0.05 significance level. Mean contrasts are shown for this parameter.
  n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

†† Means connected by the same vertical line are not different at the 0.05 significance level. Means not connected by the same line are different at the 0.05 significance level.

indicating that tissue concentration patterns were similar over time in the reference and test sediments. The mean contrast in Table 7 revealed that tissue PCB concentrations decreased statistically, rather than increased, with increasing exposure time. Indeed, after 14 days exposure, the overall mean PCB concentration (Table 7) was lower than it had been in the background tissue samples taken at the initiation of the test (Table A12). There was no apparent relationship between bulk PCB content in the sediment (Table A2) and concentration in fawnfoot clam tissues after 7 or 14 days exposure to UMR sediments (Table A12).

Three-ridge clam - *Amblema plicata*

44. No three-ridge clams died during 14 days exposure to any of the UMR sediments (Table A13).

45. Contaminant concentrations in tissues of three-ridge clams after 7 and 14 days exposure to UMR sediments are shown in Table A14. Again, Hg was below the detection limit of 0.05 µg/g wet weight in all samples. Analyses of variance showed no statistically significant effect of sediment location on tissue concentration of Cd, Pb, Cu, or Zn after 7 days of exposure (Table 8). That is, none of the test sediments produced tissue concentrations statistically different from those of clams in the Lake Polander reference sediment.

46. Results of a factorial analysis of variance to determine the influence of sediment sampling location and exposure time on total PCB concentration in three-ridge clams are presented in Table 9. This showed that there were statistically significant differences due to sediment location, but that there was no difference due to time or the interaction of time and location. These facts indicate that 14-day exposure had no advantage over 7-day exposure in indicating PCB uptake and that the pattern of tissue concentration over time was the same at all locations. The mean contrast in Table 9 revealed that three-ridge clams exposed to Lake Pepin sediment had a statistically higher mean tissue concentration of PCB than clams in the Lake Polander reference sediment or in the other test sediments. Even so, the mean concentration in clams exposed to Lake Pepin sediment (Table 9) was somewhat lower than the mean of the background clams at the beginning of the test (Table A14).

Table 7

Comparison of Total PCB Concentration in Tissue of Fawn-Foot Clam *Truncilla donaciformis* after 7 and 14 Days Exposure to Four UMR Sediments

ANOVA						Mean Contrast	
Source	DF	Sum of Squares	Mean Square	F	Significance†	Exposure Time	Mean of all Locations (PCB, μg/g wet wt)††
Location	3	0.00933	0.00311	1.32	n.s.	7 days	0.12
Time	1	0.01036	0.01036	4.39	*	14 days	0.09
Location × time	3	0.01448	0.00483	2.05	n.s.		
Error	39	0.09214	0.00236				
Total	46	0.12631					

† Entries in this column are defined as follows:
  * Statistical difference at the 0.05 significance level. Mean contrasts are shown for this parameter.
  n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

†† Means not connected by the same line are different at the 0.05 significance level.

Table 8

Comparison of Contaminant Concentrations in Tissue of Three-Ridge Clam *Amblema plicata* Exposed to Four UMR Sediments for 7 Days

Parameter	Source	DF	Sum of Squares	Mean Square	F	Significance†
Cd	Location	3	0.17096	0.05699	0.81	n.s.
	Error	10	0.69973	0.06997		
	Total	13	0.87069			
Pb	Location	3	1.22939	0.40980	3.01	n.s.
	Error	10	1.35994	0.13599		
	Total	13	2.58933			
Cu	Location	3	82.65577	27.55912	1.19	n.s.
	Error	10	232.24980	23.22498		
	Total	13	314.90557			
Zn	Location	3	1058.54762	352.84291	0.90	n.s.
	Error	10	3934.66667	393.46667		
	Total	13	4993.21429			

† Entries in this column are defined as follows:
n.s. indicates no statistical differences at the 0.05 significance level; therefore, mean contrasts were unnecessary.

Table 9

Factorial Analysis of Variance and Mean Contrast Comparing Total PCB Concentration in Tissue of Three-Ridge Clam (*Amblema plicata*) Exposed to Four UMR Sediments for 7 and 14 Days

Source	Factorial ANOVA: DF	Sum of Squares	Mean Square	F	Significance†	Mean Contrast: Location	Mean of Both Times (PCB, µg/g wet wt)††
Location	3	0.00617	0.00206	3.05	*	Lake Pepin	0.08
Time	1	0.00025	0.00025	0.36	n.s.	Mississippi River	0.05
Location × time	3	0.00171	0.00059	0.84	n.s.	Minnesota River	0.05
Error	39	0.02632	0.00067			Lake Polander (reference)	0.05
Total	46	0.03445					

† Entries in this column are defined as follows:

* Statistical difference at the 0.05 significance level. Mean contrasts are shown for this parameter.

n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

†† Means connected by the same vertical line are not different at the 0.05 significance level. Means not connected by the same line are different at the 0.05 significance level.

Catfish - *Ictalurus punctatus*

47. Fingerling channel catfish exposed to suspensions of four UMR sediments for 6 days had almost complete survival (Table A15). The only two deaths occurred during exposure to Mississippi River sediment.

48. Contaminant concentrations in tissues of catfish in the background samples and after 6 days exposure to suspensions of four UMR sediments are shown in Table A16. Concentrations of Hg in all samples exposed to test and reference sediments as well as the background samples were below the detection limit of 0.05 μg/g wet weight. Analysis of variance tables comparing concentrations of the other contaminants among tissues of catfish in the initial background sample and catfish exposed to suspensions of the four UMR sediments for 6 days are presented in Table 10. There were no statistically significant differences in concentrations of Pb or Zn among catfish exposed to the test and reference sediments and in the initial background sample. Zinc concentrations in the initial background catfish sample were exceeded only by concentrations in fish in suspensions of the reference sediment (Table A16), although the differences were not statistically significant. In the cases of both Pb and Zn, the initial background value was between the highest and lowest mean value for exposed catfish. There was no apparent relationship between concentrations of Pb and Zn in unfiltered water (Table A4) and concentrations in catfish tissues (Table A16). Nor was there any apparent relationship between Zn in solution in water filtered from the suspensions (Table A5) and Zn in tissues of catfish exposed to the suspensions for 6 days (Table A16).

49. Exposure of catfish to suspensions of the four UMR sediments for 6 days caused statistically significant differences in tissue concentrations of total PCB, Cd, and Cu. Mean contrasts for these parameters are presented in Table 10. There were no statistically significant differences in total PCB concentration between the initial background sample of catfish and those exposed to suspensions of the Lake Polander reference sediment or Minnesota River or Lake Pepin sediments. Total PCB was statistically higher in catfish exposed to suspensions of Mississippi River sediment than in the initial background

Table 10

Comparison of Contaminant Concentrations in Tissues of Channel Catfish *Ictalurus punctatus* Exposed to Suspensions of Four UMR Sediments for 6 Days

Parameter	Analyses of Variance: Source	DF	Sum of Squares	Mean Square	F	Significance†	Mean Contrasts: Location	Mean††
								(PCB, µg/g wet wt)
Total PCB	Location	4	0.00428	0.00107	3.56	*	Mississippi River	0.05
	Error	24	0.00722	0.00030			Lake Polander (reference)	0.04
	Total	28	0.01150				Minnesota River	0.02
							Background	0.02
							Lake Pepin	0.02
								(Cd, µg/g dry wt)
Cd	Location	4	0.00724	0.00181	6.66	**	Mississippi River	0.0725
	Error	24	0.00653	0.00027			Lake Polander (reference)	0.0404
	Total	28	0.01378				Background	0.0315
							Minnesota River	0.0293
							Lake Pepin	0.0280
Pb	Location	4	0.17828	0.04457	2.34	n.s.		
	Error	24	0.45697	0.01904				
	Total	28	0.63525					
								(Cu, µg/g dry wt)
Cu	Location	4	4.33977	1.08494	7.22	**	Lake Polander (reference)	2.43
	Error	24	3.60749	0.15031			Background	1.79
	Total	28	7.94726				Mississippi River	1.63
							Minnesota River	1.50
							Lake Pepin	1.32
Zn	Location	4	767.99167	191.99792	1.33	n.s.		
	Error	24	3463.50833	144.31285				
	Total	28	4231.50000					

† Entries in this column are defined as follows:
- * Statistical difference at the 0.05 significance level. Mean contrasts are shown for this parameter.
- ** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.
- n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

†† Means connected by the same vertical line are not different at the 0.05 signficance level. Means not connected by the same line are different at the 0.05 significance level.

sample. Even so, the mean concentration in catfish exposed to Mississippi River sediment for 6 days was identical to the mean concentration in the final background sample on day 6 (Table A16). The PCB concentration in all unfiltered water samples was below the analytical detection limit of 0.05 μg/ℓ (Table A4), so any relationships between unfiltered water concentration and tissue concentration were not determinable. Mean Cd concentration in catfish exposed to suspensions of Mississippi River sediment was statistically higher than in the initial background sample or fish exposed to suspensions of the Lake Polander reference or the other two test sediments (Table 10). The mean concentration of Cu in catfish exposed to suspensions of the Lake Polander reference sediment for 6 days was statistically greater than mean concentrations in fish in the three test sediments, none of which differed statistically from the initial background sample (Table 10). Tissue concentrations of Cu in fish exposed to Mississippi and Minnesota River and Lake Pepin sediments were bracketed by concentrations in the initial and final background samples (Table A16). Mean Cu concentration in Lake Polander fish was less than twice the concentration in the lower background sample mean. The Lake Polander sediment suspensions had a higher Cu concentration than suspensions of the other sediments (Table A4), as well as the highest mean Cu value in exposed catfish (Table A16). Even so, there was no apparent relationship between Cu concentrations in suspensions and in catfish tissue, since the suspension with the second highest concentration gave the lowest mean tissue concentration and the suspensions with the lowest concentrations gave intermediate mean tissue values (Tables A4 and A16).

Bluegill - *Lepomis macrochirus*

50. Table A17 indicates that some mortality occurred among bluegills exposed to suspensions of all four UMR sediments for 6 days. An analysis of variance of these data (Table 11) showed no statistically significant differences in survival among bluegills exposed to the reference and the three test sediments.

51. Contaminant concentrations in tissues of bluegills in the background sample and after 6 days of exposure to SPP of UMR sediments

are presented in Table A18. Both Hg and the PCB Arochlor 1016 were below analytical detection limits in the background sample and in all samples analyzed after exposure to the test and reference sediments.

52. Analysis of variance tables comparing concentrations of total PCB, Cd, Pb, Cu, and Zn among the background samples and bluegills exposed to suspensions of the four UMR sediments are presented in Table 12. There were no statistical differences in Pb concentrations among fish in the background sample and those exposed to the Lake Polander reference or the three test sediments. The mean of the background slightly exceeded the mean values for bluegills exposed to suspensions of the Minnesota River and reference sediments (Table A18).

53. Mean contrasts (Table 12) were performed for those parameters showing statistically significant differences among sediments. Mean PCB concentration in bluegills exposed for 6 days to suspensions of Mississippi River sediment was statistically higher than in fish in the background sample and those exposed to the Lake Polander reference or the other two test sediments. Bluegills exposed to Lakes Pepin and Polander and Minnesota River sediments did not differ in PCB concentration from those in the background sample. Concentrations of Cd in bluegills exposed to suspensions of Lake Pepin and Mississippi River sediments were not statistically different, but both were statistically higher than concentrations in bluegills in the background sample and those exposed to the Lake Polander reference and the Minnesota River sediment (Table 12). There was no apparent relationship between Cd concentration in the suspensions (Table A4) and in tissues of bluegills (Table A16). Six days exposure to suspensions of all three of the UMR test sediments produced tissue Cu concentrations statistically higher than did exposure to the Lake Polander reference sediment (Table 12). However, the background sample contained slightly higher Cu concentrations than fish in any of the four UMR sediments. Mean Zn concentrations were not statistically different in bluegills exposed to suspensions of Mississippi River and Lake Pepin sediments, but both were statistically higher than in bluegills in the background sample (Table 12). Suspensions of the Lake Polander reference sediment and Minnesota River sediment produced

Table 11

Analysis of Variance Table Comparing Survival of Bluegill *Lepomis macrochirus* Exposed to Suspensions of UMR Sediments for 6 Days

Species	Source	DF	Sum of Squares	Mean Square	F	Significance†
Bluegill	Location	3	5.45833	1.81944	2.25	n.s.
	Error	20	16.16667	0.80833		
	Total	23	21.62500			

† Entries in this column are defined as follows:
n.s. indicates no statistical differences at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

Table 12

Comparisons of Contaminant Concentrations in Tissues of Bluegill *Lepomis macrochirus* Exposed to Suspensions of Four UMR Sediments for 6 Days

Parameter	Analyses of Variance: Source	DF	Sum of Squares	Mean Square	F	Significance†	Mean Contrasts: Location	Mean††
								(PCB, µg/g wet wt)
Total PCB	Location	4	0.00454	0.00113	4.57	**	Mississippi River	0.05
	Error	24	0.00596	0.00025			Lake Polander (reference)	0.03
	Total	28	0.01050				Background	0.02
							Lake Pepin	0.02
							Minnesota River	0.02
								(Cd, µg/g wet wt)
Cd	Location	4	0.01332	0.00333	6.97	**	Lake Pepin	0.0732
	Error	24	0.01151	0.00048			Mississippi River	0.0655
	Total	28	0.02484				Lake Polander (reference)	0.0313
							Minnesota River	0.0273
							Background	0.0206
Pb	Location	4	0.11749	0.02937	1.35	n.s.		
	Error	24	0.52071	0.02170				
	Total	28	0.63820					
								(Cu, µg/g dry wt)
Cu	Location	4	4.69451	1.17363	3.65	*	Background	2.79
	Error	23	7.39996	0.32174			Mississippi River	2.78
	Total	27	12.09447				Lake Pepin	2.34
							Minnesota River	2.22
							Lake Polander (reference)	1.64
								(Zn, µg/g dry wt)
Zn	Location	4	19,388.36523	4847.09131	5.50	**	Mississippi River	211
	Error	24	21,158.81467	881.61840			Lake Pepin	210
	Total	28	40,547.20690				Minnesota River	180
							Background	170
							Lake Polander (reference)	142

† Entries in this column are defined as follows:
* Statistical difference at the 0.05 significance level. Mean contrasts are shown for this parameter.
** Statistical difference at the 0.01 significance level. Mean contrasts are shown for this parameter.
n.s. No statistical difference at the 0.05 significance level; therefore, determination of mean contrasts was unnecessary.

†† Means connected by the same vertical line are not different at the 0.05 significance level. Means not connected by the same line are different at the 0.05 significance level.

bluegill Zn concentrations not statistically different from the background Zn concentrations. There was no apparent relationship between Zn concentration in bluegills exposed to suspended sediments (Table A18) and Zn concentration in the suspensions (Table A4) or in water filtered from those suspensions (Table A5).

General Discussion

54. The evaluation of results derived from a study of bioaccumulation potential should be governed by proper scientific and statistical procedures and an assessment of the ecological significance of the findings. Proper statistical procedures applied to sound scientific experimentation should ensure representative data with adequate reliability to provide enough sensitivity for testing for significant differences among experimental treatments. However, variability associated with a technique of measurement can mask true differences among treatments by increasing the estimated experimental error independent of errors associated with experimental units or treatment effects. In this study, the results indicate that in most cases the number of replicate samples were sufficient relative to the estimated experimental error to demonstrate statistically significant differences between test sediments and the reference or background values to which they were compared. However, caution must be used in the analysis and interpretation of data when dealing with extremely low contaminant concentrations that approach analytical detection limits. The analytical state of the art is such that individual analyses are not precisely reproducible. This is indicated by the variability exhibited between portions of selected samples that were split in an effort to assess analytical reliability (Tables A2, A16, A18). It is also apparent from results of this study that the range of variability is not consistent. Because of this, it is difficult to obtain consistently reliable estimates of the true experimental error based on a limited number of replicate samples taken at any given time and location. If day-to-day variations in the sensitivity and precision of state of the art analytical techniques cause the estimated

experimental error to be biased, basic assumptions of the statistics used to test for significant differences may be violated. This situation requires that small absolute differences among sample means near the analytical detection limit be interpreted with caution despite an apparent demonstration of statistical significance. The likelihood of environmental damage probably is less when only small differences exist between reference sediments or background values and test sediments with low contaminant concentrations, even though the probability of an error in data interpretation may be greater.

55. As emphasized by the Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material (1978), it is essential to recognize that dredged material bioassays cannot be considered precise predictors of environmental effects. This is true since the inherent differences between laboratory and field conditions require an objective but nonquantitative extrapolation from laboratory data to the prediction of effects in the field. The data analyses in this report take the environmentally protective approach of comparing responses of water-column organisms in suspensions of test sediment to responses of animals in contaminant-free tap water, rather than somewhat more contaminated ambient Upper Mississippi River water. The response of benthic animals in deposits of test sediment was compared to animals in contaminant-free water and a reference sediment selected because of its demonstrated environmental acceptability in the field. Since test animals were compared to animals in very clean conditions, if no statistically significant differences occurred, there is little reason to suspect effects to occur in the potentially somewhat more contaminated natural conditions of the Upper Mississippi River. On the other hand, the occurrence of statistically significant differences in these laboratory studies cannot necessarily be taken as a prediction that an ecologically important impact would occur in the field (Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material, 1978). Such a laboratory finding does indicate the potential for effects to occur in the field. In order to extrapolate the laboratory data to the field and evaluate

the likelihood of that potential being realized, it is necessary to consider the fact that the laboratory comparison was made to clean water rather than ambient river water, the lack of dilution in the lab relative to the field, exposure times in the lab and field, the magnitude of the effect shown, the number of species affected by any particular sediment, and other factors relevant to the dredging and disposal operation in question.

56. In view of the above general considerations applicable to interpretation of any type of laboratory biological evaluation, it is especially difficult to determine whether contaminant concentrations found in tissues of experimental animals are of potential ecological importance. The existence of statistically significant differences in tissue contaminant concentrations between organisms exposed to the test and reference sediments or background conditions does not necessarily imply that dredging of the test sediment is likely to cause unacceptable levels in tissues of organisms in the vicinity of the operation. It simply indicates a potential for tissue concentration to be increased in field organisms. To make a judgment on the likelihood of this potential being fulfilled requires a knowledge of contaminant levels in similar organisms living in the disposal vicinity, relative levels in exposed and background organisms in the laboratory study, the number of species and contaminants involved in bioaccumulation from any particular sediment, the toxicological importance of the material(s) bioaccumulated, levels found in similar species in other contaminated and uncontaminated areas, and relevant action levels.

57. In most cases the state of scientific knowledge is inadequate to quantify the consequences of a given concentration of a bioaccumulated constituent in the tissues of an animal. Part of the reason for this is that animals vary in uptake mechanisms and sensitivity to various contaminants with species, age, sex, reproductive state, and physiological condition. For instance, Cu and Zn are essential micronutrients that are required at low levels by all species and become toxic only when much higher concentrations are accumulated in the tissues. Others, such as Cd, Pb, Hg, and the chlorinated hydrocarbons, must be viewed as

potentially hazardous when bioaccumulated, even though they may sometimes be found at very low levels even in animals from environments far removed from any direct contaminant sources.

58. Because of the absence of adequate information for ecological evaluation of species tissue concentrations of contaminants, FDA action levels provide the most objective basis for evaluation. These levels are established by a Federal rule-making process and are intended to protect the health of human consumers of fish and shellfish, or other commodities. Therefore, they are a valid basis for interpreting the potential human hazard of bioaccumulation. Of the contaminants evaluated in this study, only Hg and PCB have FDA action levels for fish and shellfish.

59. Since the ecological significance of a given tissue concentration in a given species is difficult to determine, interpretation of bioaccumulation data is usually based on a comparison of tissue concentrations of exposed animals relative to tissue concentrations in reference or background animals of the same species. In using this approach, it is necessary to recognize the possibility that background or reference animals could have an undesirably high tissue concentration prior to testing, or, that even the highest concentration found in the exposed animals at the end of the test might not be sufficient to be of ecological importance.

60. There was considered to be an indication of bioaccumulation potential when concentrations in the tissues of exposed fish statistically exceeded concentrations in the background sample, or when tissue concentration in clams in the test sediments statistically exceeded concentrations in clams in the reference sediment. By this criterion there was an indication of potential bioaccumulation of PCB in catfish *I. punctatus* and bluegills *L. macrochirus* exposed to suspensions of Mississippi River sediment and three-ridge clams *A. plicata* exposed to Lake Pepin sediment. However, the highest mean PCB concentration in exposed catfish did not exceed the day 6 background value and the highest mean concentration in exposed three-ridge clams was lower than the mean background concentration.

61. Cadmium concentrations statistically exceeded background levels in catfish *I. punctatus* exposed to suspensions of Mississippi River sediment and in bluegills *L. macrochirus* in suspensions of Lake Pepin and Mississippi River sediments. These were the only indications of potential Cd bioaccumulation, as Cd values in both clams exposed to the test sediments did not statistically exceed concentrations in the reference clams.

62. Only in bluegills *L. macrochirus* were Zn tissue concentrations statistically higher in animals exposed to test sediments than in the background samples. Zinc concentrations in bluegills exposed to suspensions of Mississippi River and Lake Pepin sediments statistically exceeded the mean initial background value. This is an indication of Zn bioaccumulation potential by bluegills from suspensions of these sediments.

63. There were no statistically significant differences in Pb or Cu concentrations between organisms exposed to any UMR test sediment and animals in the reference sediment or background samples, as appropriate, for any species studied. Concentrations of Hg were below the detection limit of 0.05 μg/g wet weight in all samples of both test and reference animals. Thus, there was no indication of bioaccumulation of either Pb, Cu, or Hg by any species exposed to any sediment.

64. Fawnfoot clams *T. donaciformis* gave no indication of bioaccumulation potential for any of the contaminants studied from any of the three UMR test sediments. Three-ridge clams *A. plicata* gave an indication of bioaccumulation potential only of PCB from the Lake Pepin sediment. Channel catfish *I. punctatus* indicated bioaccumulation potential only for Cd and PCB from suspensions of the Mississippi River sediment. Bluegills *L. macrochirus* showed bioaccumulation potential for PCB, Cd, and Zn from suspensions of Mississippi River sediment, and Cd and Zn from Lake Pepin sediment.

65. Mississippi River sediment indicated potential bioaccumulation of PCB Cd by catfish *I. punctatus* and PCB, Cd, and Zn by bluegills. Lake Pepin sediment exposure gave an indication of bioaccumulation potential of PCB by three-ridge clams *A. plicata* and Cd and Zn by bluegills.

66. The bioaccumulation potential study included four species, three test sediments, and six contaminants for a total of 72 cases (18 per species) where bioaccumulation might have been detected. Of these possibilities, bioaccumulation potential was not indicated at all in fawnfoot clams; there was one indication (6 percent of the possible cases) in three-ridge clams, two indications (11 percent of the possible cases) in catfish, and five indications (28 percent of the possible cases) in bluegills. Out of the total of 72 possible cases where bioaccumulation potential might have been found, it was indicated eight times (11 percent of the possible cases).

67. The PCB concentration in three-ridge clams exposed to Lake Pepin sediment was statistically higher than in clams exposed to the Lake Polander reference sediment; yet, the mean background value prior to exposure was higher than the means for the exposed clams. These data indicate that exposure to the test sediments did result in tissue PCB concentrations statistically higher than those in clams from a UMR area presumably free of PCB sources and contamination. However, the highest mean PCB concentration in any exposed three-ridge clam sample, 0.08 μg/g wet weight in clams exposed to Lake Pepin sediment for 7 days, was 62 times lower than the action level of 5 μg/g for PCB in fish and shellfish set by the FDA (Department of Health, Education, and Welfare 1979).

68. After 6 days exposure to suspensions of Mississippi River sediment, catfish had PCB concentrations statistically higher than fish in the initial background sample. However, the highest mean concentration in exposed fish did not exceed the background mean at the end of the test. This indicates that exposure to suspensions of the UMR sediments did not result in catfish tissue PCB levels higher than those occurring in some catfish raised in a hatchery environment presumably relatively free of PCB sources and contamination. The highest mean level in exposed catfish was 0.05 μg/g wet weight after exposure to suspensions of Mississippi River sediment, which is 100 times lower than the FDA action level of 5 μg/g (Department of Health, Education, and Welfare 1979). Bluegills showed statistically greater PCB concentrations after 6 days exposure to Mississippi River suspensions than in background fish.

However, the highest mean PCB value in exposed bluegills (0.05 μg/g wet weight) was only 2.5 times the background level in bluegill raised in a hatchery environment presumably relatively free of PCB sources and contamination. This level was also 100 times lower than the FDA action level of 5 μg/g (Department of Health, Education, and Welfare 1979).

69. The U. S. Environmental Protection Agency's 1972 Water Quality Criteria (National Academy of Sciences-National Academy of Engineering Committee on Water Quality Criteria 1973) states, "Aquatic life should be protected where the maximum concentration of total PCB...residues in the general body tissues of any aquatic organism do not exceed 0.5 microgram per gram." The highest mean PCB value in exposed clams was 0.13 μg/g and the highest in fish was 0.05 μg/g, which are 4 and 10 times lower, respectively, than the tissue concentration level considered adequate for the protection of aquatic life by the National Academy of Sciences. All of these factors indicate that exposure to the UMR test sediments resulted in tissue concentrations of PCB well below levels indicating real potential for unacceptable adverse impacts.

70. Mercury was below the detection limit of 0.05 μg/g wet weight in all tissue samples analyzed. Thus, there was no indication that exposure to the UMR test sediments had any influence on Hg content of the species studied. Even if one makes the environmentally conservative assumption that concentrations in tissues of all organisms exposed to the test sediments were only slightly below the detection limit, this would still be 20 times lower than the FDA action level of 1.0 ppm for Hg in edible fish and shellfish (Department of Health, Education, and Welfare 1978).

71. The Minnesota River sediment was the least toxic of the four UMR sediments to five of the seven species tested, but was the second most toxic to one of the others. It caused the highest mortalities of *Hexagenia limbata*, but this was probably not due to chemical toxicity but rather physical incompatibility of the species with the sandy sediment. Mississippi River sediment was the most toxic of the UMR sediments to four of the six species with which it was tested. It caused no mortality of three-ridge clams and was of intermediate toxicity to

Daphnia magna. The Lake Pepin sediment and the Lake Polander reference sediment were of intermediate and varying toxicity to different species. Although statistical comparisons were not made, it appeared that the UMR test sediments caused mortality of amphipods *Hyallela azteca* above that in controls but not above that in the reference sediment (Table A6). Mayfly larvae *Hexagenia limbata* suffered mortality (Table A7) but this was apparently due to physical causes. *Daphnia magna* suffered some mortality when exposed to SPP of UMR test sediments, but, in both experiments 1 and 2, no UMR sediment produced mortality statistically greater than both controls after 96 hr or more of exposure (Tables 4 and 5). No mortality of either species of clam or fish could be attributed to exposure to the UMR sediments (Tables 11, A11, A13, and A15).

PART IV: CONCLUSIONS

72. The experimental conditions were selected to approximate those that might be experienced by organisms in the vicinity of a typical UMR area dredging and disposal operation. *Daphnia* and the fish were exposed to suspended sediments for times approximating the longest duration of an average dredging and disposal operation. The amphipods and mayfly larvae were exposed to the deposited sediment for sufficient time periods that mortality occurred. Clam exposures were sufficient for bioaccumulation to have been detected if it was going to occur, as demonstrated by experience with shorter exposures in the ocean dumping regulatory program for dredged material. Based upon the experimental results and the discussion presented above, the following conclusions may be drawn from this study.

a. The three UMR test sediments did not produce statistically greater mortality of *Daphnia* than the controls. There was no statistically significant mortality of fish or clams under any experimental conditions. Mortality data for the other benthic organisms gave no indication that any of the three UMR test sediments were any more toxic than the reference sediment, selected for use because of its demonstrated environmental acceptability in the field.

b. Bioaccumulation potential of contaminants as a result of exposure to test sediments was indicated in a definite minority (11 percent) of the possible cases.

c. Even where bioaccumulation potential was indicated, tissue concentrations remained well below established FDA action levels. They were also below the maximum tissue concentration considered acceptable for the protection of aquatic life by the 1972 EPA Water Quality Criteria.

d. This study has provided no indication that dredging and open-water disposal of the UMR sediments studied would affect mobility of the sediment-associated chemicals in such a way as to result in demonstrable ecologically adverse effects on survival or tissue concentrations of contaminants in the test species.

REFERENCES

American Public Health Association, American Water Works Association, Water Pollution Control Federation. 1975. Standard Methods for the Examination of Water and Wastewater, 14th ed., Washington, D. C.

Baker, A. M., and D. F. Fraser. 1976. "A Method for Securing the Gut Contents of Small, Live Fish," Trans. Am. Fish. Soc. Vol 1976, No. 4, pp 520-522.

Bertine, K. K., and E. D. Goldberg. 1972. "Trace Elements in Clams, Mussels, and Shrimp," Limnol. Oceanogr., Vol 17, pp 877-884.

Department of Health, Education, and Welfare, Food and Drug Administration. 1975. Pesticide Analytical Manual, Vol I, Washington, D. C.

Department of Health, Education, and Welfare, Food and Drug Administration. 1978. "Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed," Industry Guidance Branch, Bureau of Foods, Washington, D. C. 14 pp.

Department of Health, Education, and Welfare, Food and Drug Administration. 1979. "Unavoidable Contaminants in Food for Human Consumption and Food-Packaging Materials; Polychlorinated Biphenyls (PCB's); Reduction of Tolerances; Confirmation of Effective Date and Partial Stay," Federal Register Part XII, Vol 44, No. 195, Friday, October 5.

DiSalvo, L. H., H. E. Guard, N. D. Hirsch, and J. Ng. 1977. "Assessment and Significance of Sediment-Associated Oil and Grease in Aquatic Environments," Technical Report D-77-26, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Environmental Protection Agency. 1974. "Methods for the Chemical Analysis of Water and Wastes," Environmental Monitoring and Surveillance Laboratory, Cincinnati, Ohio.

Environmental Protection Agency. 1977. "Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants," Environmental Monitoring and Surveillance Laboratory, Cincinnati, Ohio.

Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material. 1978. "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters; Implementation Manual for Section 103 of Public Law 92-532 (Marine Protection, Research, and Sanctuaries Act of 1972)," July 1977 (Second Printing April 1978), Environmental Effects Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Flegal, A. R., and J. H. Martin. 1977. "Contamination of Biological Samples by Ingested Sediment," Mar. Poll. Bull., Vol 8, pp 90-92.

National Academy of Sciences-National Academy of Engineering Committee on Water Quality Criteria. 1973. Water Quality Criteria 1972, U. S. Environmental Protection Agency, Ecological Research Series EPA-R3-73-033.

Olson, G. F. et al. 1975. "Mercury Residues in Fathead Minnows, *Pimphales promelas* Rafinesque, Chronically Exposed to Methylmercury in Water," Bull. Environ. Contam. Toxicol., Vol 14, No. 2.

Patrick, W. H. 1958. "Modification of Method of Particle Size Analysis," Soil Science Soc. of America Proceedings, Vol 22, No. 4, pp 366-367.

Peddicord, R. K., and V. A. McFarland. 1978. "Effects of Suspended Dredged Material on Aquatic Animals," Technical Report D-78-29, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Poldoski, J. E., and G. E. Glass. 1975. Proceedings of the International Conference on Heavy Metals in the Environment, Toronto, Ontario, Canada, October 17-31, pp 901-922.

Shuba, P. J., H. E. Tatem, and J. H. Carroll. 1978. "Biological Assessment Methods to Predict the Impact of Open-Water Disposal of Dredged Material," Technical Report D-78-50, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Thompson, J. F., ed. 1977. "Analyses of Pesticide Residues in Human and Environmental Samples," Manual of Analytical Methods, Environmental Protection Agency, National Environmental Research Center, Research Triangle Park, North Carolina.

APPENDIX A: RAW DATA TABLES

Table A1

Particle-Size Analyses of the Four UMR* Sediments Used in the Bioassay-Bioaccumulation Studies

Sediment	$\frac{\text{Dry wt}}{\text{Wet wt}}$	Replicate	Percentage Composition		
			Sand (>50 μ)	Silt (2-50 μ)	Clay (<2 μ)
Minnesota River	0.70	1	67	13	21
		2	65	13	21
		Mean	66	13	21
Mississippi River	0.54	1	55	15	30
		2	55	15	30
		3	55	15	30
		Mean	55	15	30
Lake Pepin	0.55	1	35	22	43
		2	32	22	44
		3	32	25	44
		Mean	33	23	44
Lake Polander (reference)	0.53	1	18	20	62
		2	18	20	62
		3	20	20	62
		Mean	18	20	62

* UMR = Upper Mississippi River.

Table A2

Bulk or Total Concentrations of Chemical Constituents in Test Sediment from Four UMR Locations

			Location			
Parameter*	Units	Replicate	Minnesota River	Mississippi River	Lake Pepin	Lake Polander (Reference)
PCB	μg/g (ppm) wet wt					
A1016		1	0.002	0.020	0.004	0.001
		2	0.002	0.020	0.005	0.002
		3	0.003	0.020	0.007	0.002
		Mean	0.002	0.020	0.005	0.002
A1254		1	0.005	0.060	0.050	0.020
		2	0.006	0.080	0.060	0.020
		3	0.008	0.070	0.070	0.020
		Mean	0.006	0.070	0.060	0.020
Total		1	0.007	0.080	0.054	0.021
		2	0.008	0.100	0.065	0.022
		3	0.011	0.090	0.077	0.022
		Mean	0.009	0.090	0.065	0.022
Hg	μg/g (ppm) wet wt	1	<0.044**	0.128	0.083	<0.050**
		2	0.026	0.100	0.071	<0.054**
		3	0.023	0.125	0.078	<0.062**
		Mean	0.031	0.118	0.077	<0.055

(Continued)

* PCB, Hg, Pb, Cu, and Zn determined by U. S. Environmental Protection Agency (EPA), others determined by U. S. Army Engineer Waterways Experiment Station Environmental Laboratory (EL).

** In calculating the mean, the concentration was assumed to be at the detection limit.

(Sheet 1 of 5)

Table A2 (Continued)

Parameter	Units	Replicate†	Location: Minnesota River	Mississippi River	Lake Pepin	Lake Polander (Reference)
Pb	μg/g (ppm) dry wt	1a	<31**	<36**	<32**	44
		1b		133		
		2a	59	180	<31**	161
		2b		<40**		
		3a	43	100	36	95
		3b			89	
		Mean	44	104††	42††	100
Cu	μg/g (ppm) dry wt	1a	13.3	24.5	21.8	19.0
		1b		27.7		
		2a	8.1	23.8	22.9	17.7
		2b		22.9		
		3a	13.5	26.3	22.9	18.6
		3b			28.7	
		Mean	12.0	25.3††	23.5††	18.4
Zn	μg/g (ppm) dry wt	1a	37.8	85.3	82.1	67.6
		1b		94.0		
		2a	33.0	95.3	90.8	69.7
		2b		77.8		
		3a	29.3	104.0	87.9	73.3
		3b			98.9	
		Mean	33.4	93.4††	88.8††	70.2

(Continued)

** In calculating the mean, the concentration was assumed to be at the detection limit.
† Notation a and b indicate sample was split and portions analyzed separately.
†† Values for split samples were averaged and treated as the datum for that sample in calculating the mean of the three samples.

(Sheet 2 of 5)

Table A2 (Continued)

Parameter	Units	Replicate	Location: Minnesota River	Mississippi River	Lake Pepin	Lake Polander (Reference)
Cd	μg/g (ppm) dry wt	1	1.18	4.50	4.00	2.22
As	μg/g (ppm) dry wt	1	2.54	2.30	3.15	2.24
Cr	μg/g (ppm) dry wt	1	28.7	54.7	63.6	48.3
Fe	percent dry wt	1	1.07	1.60	2.28	1.97
Mn	μg/g (ppm) dry wt	1	419	652	879	672
Ni	μg/g (ppm) dry wt	1	16.7	24.0	30.1	25.0
Total phosphorus (TP)	μg/g (ppm) dry wt	1	561	867	951	867
Total Kjeldahl nitrogen (TKN)	μg/g (ppm) dry wt	1	740	1870	1690	1960
Ammonia nitrogen (NH_3-N)	μg/g (ppm) dry wt	1	100	210	140	60
Total solids (TS)	percent dry wt	1	69.8	54.7	50.4	50.4

(Continued)

Table A2 (Continued)

Parameter	Units	Replicate	Location: Minnesota River	Mississippi River	Lake Pepin	Lake Polander (Reference)
Total volatile solids (TVS)	percent dry wt	1	1.55	2.44	2.98	2.57
Total organic carbon (TOC)	mg/g (ppt) dry wt	1	5.85	11.00	12.40	11.50
Chemical oxygen demand (COD)	percent dry wt	1	1.97	2.70	8.98	5.20
Cyanide (CN)	μg/g (ppm) dry wt	1	<0.4	<0.4	<0.4	<0.4
Sulfur (S)	μg/g (ppm) dry wt	1	<5	38	47	10
Oil and grease	μg/g (ppm) dry wt	1	800	230	710	420
Naphthalene	μg/g (ppm) dry wt	1	<0.010	<0.015	<0.010	0.015
Methylnaphthalene	μg/g (ppm) dry wt	1	<0.010	<0.010	<0.010	<0.010
Total DDT	μg/g (ppm) dry wt	1	<0.004	<0.004	<0.004	<0.004
Lindane	μg/g (ppm) dry wt	1	<0.001	<0.001	<0.001	<0.001

(Continued)

(Sheet 4 of 5)

Table A2 (Concluded)

			Location			
Parameter	Units	Replicate	Minnesota River	Mississippi River	Lake Pepin	Lake Polander (Reference)
Heptachlor	μg/g (ppm) dry wt	1	<0.001	<0.001	<0.001	<0.001
Heptachlor epoxide	μg/g (ppm) dry wt	1	<0.001	<0.001	<0.001	<0.001
Aldrin	μg/g (ppm) dry wt	1	<0.001	<0.001	<0.001	<0.001
Endrin	μg/g (ppm) dry wt	1	<0.001	<0.001	<0.001	<0.001
Dieldrin	μg/g (ppm) dry wt	1	<0.001	<0.001	<0.001	<0.001

(Sheet 5 of 5)

Table A3

Concentrations of Chemical Constituents in Unfiltered Water Samples from the Clam Experiments*

Sediment	Replicate	Total PCB	Hg	Cd	Cu	Cr	Pb	Zn
Lake Pepin	1	--	--	--	--	--	--	13
	2	--	--	--	--	--	--	--
	3	--	--	--	--	--	--	--
	4	--	--	--	--	--	--	--
	5	--	--	--	--	--	--	--
	6	--	--	--	--	--	--	--
	Mean							13
Minnesota River	1	--	--	--	--	--	--	--
	2	--	--	--	10	--	--	--
	3	--	--	--	--	--	--	--
	4	--	--	--	--	--	--	--
	5	--	--	--	--	--	--	--
	6	--	--	--	--	--	--	11
	Mean				10			11
Mississippi River	1	--	0.7	--	--	--	--	--
	2	--	--	--	--	--	--	--
	3	--	--	--	--	--	--	12
	4	--	--	--	--	--	--	--
	5	--	--	--	--	--	--	--
	6	--	--	--	--	--	--	--
	Mean		0.7					12
Lake Polander (reference)	1	--	--	--	--	--	--	--
	2	--	--	--	--	--	--	--
	3	--	--	--	--	--	--	--
	4	--	--	--	--	--	--	--
	5	--	--	--	--	--	--	--
	6	--	--	--	--	--	--	--
	Mean							
Background	1	--	--	--	--	--	--	--
	2	--	--	--	--	--	6	12
	3	--	--	--	--	--	--	14
	4	--	--	--	--	--	--	10
	Mean						6	12
Deionized water	1	--	--	--	--	--	--	--
	2	--	--	--	--	--	--	--
Detection limits		0.1	0.5	0.1	10	2	3	10

* All measurements in micrograms per litre (ppb). Entry -- indicates concentrations below detection limits.

Table A4

Concentrations of Chemical Constituents in Unfiltered Water from the Fish Experiment*

Treatment	Replicate	Total PCB	Hg**	Cd	Cu	Cr	Pb	Zn
Lake Pepin	1	--		0.5	22	6	7	38
	2	--		0.5	36	5	11	52
	3	--		0.3	24	12	10	53
	4	--		0.3	20	5	8	47
	5	--		0.3	--	3	7	75
	6	--		0.5	20	7	8	41
	Mean			0.4	24	6	9	51
Minnesota River	1	--		0.2	28	2	7	72
	2	--		0.1	15	4	6	30
	3	--		0.2	14	2	8	47
	4	--		0.2	14	5	5	30
	5	--		0.2	21	--	7	40
	6	--		0.1	15	--	6	35
	Mean			0.2	18	3	7	42
Mississippi River	1	--		0.7	17	6	10	34
	2	--		0.5	20	2	8	40
	3	--		0.5	14	3	11	30
	4	--		0.6	15	4	7	32
	5	--		0.8	22	6	11	52
	Mean			0.6	18	4	9	38
Lake Polander (reference)	1	--		0.1	23	5	7	54
	2	--		0.2	14	2	6	30
	3	--		0.1	14	--	6	37
	4	--		0.2	79	4	7	42
	5	--		0.1	--	--	3	18
	6	--		--	16	--	4	17
	Mean			0.1	29	4	6	25
Detection limit		0.05	0.5	0.1	10	2		

* All measurements in micrograms per litre (ppb). Entry -- indicates concentrations below detection limits.

** See discussion of Hg results in text (paragraph 33).

Table A5

Concentrations of Chemical Constituents in Filtered Water from the Fish Experiment*

Treatment	Replicate	Total PCB	Hg	Cd	Cu	Cr	Pb	Zn
Lake Pepin	1	--	0.7	--	16	--	--	26
	2	--	0.8	--	13	--	--	19
	3	--	--	--	--	--	--	17
	4	--	0.5	--	--	--	--	17
	5	--	--	--	--	--	--	21
	6	--	--	--	--	--	--	21
	Mean		0.7		15			20
Minnesota River	1	--	--	--	--	--	--	23
	2	--	--	--	10	--	--	18
	3	--	--	--	--	--	--	20
	4	--	--	--	--	--	--	43
	5	--	--	--	--	--	--	13
	6	--	--	--	--	--	--	15
	Mean				10			22
Mississippi River	1	--	--	--	--	--	--	19
	2	--	--	--	--	--	--	18
	3	--	--	--	--	--	--	13
	4	--	--	--	--	--	--	14
	5	--	--	--	--	--	--	19
	Mean							17
Lake Polander (reference)	1	--	--	--	--	--	--	18
	2	--	--	--	--	--	--	16
	3	--	--	--	--	--	--	15
	4	--	--	--	--	--	--	14
	5	--	--	--	--	--	--	--
	6	--	--	--	--	--	--	13
	Mean							15
Background	1	--	--	--	--	--	--	10
	2	--	--	--	--	--	--	--
	3	--	--	--	--	--	--	12
	4	--	--	--	--	--	--	--
	Mean							11
Deionized water	1	--	--	--	--	--	--	--
	2	--	--	--	--	--	--	--
Detection limits		0.05	0.5	0.1	10	2	3	10

* All measurements in micrograms per litre (ppb). Entry -- indicates concentrations below detection limits.

Table A6

Survival of Amphipod *Hyalella azteca* Exposed to Various Sediments for 10 Days

Treatment	Replicate	Survival*
Control	1	20
	2	20
	Mean	20
Minnesota River	1	15
	2	16
	Mean	15
Lake Pepin	1	17
	2	9
	Mean	13
Lake Polander (reference)	1	11
	2	9
	Mean	10
Mississippi River	1	8
	2	7
	Mean	7
VC** sediment	1	0
	2	0
	Mean	0

* Tests were initiated with 20 organisms per replicate.
** Vicksburg, Mississippi, area sediment.

Table A7

Survival of Mayfly Larvae *Hexagenia limbata* Exposed to Three UMR Sediments for 11 Days

Sediment	Exposure Time - Survival					
	Day 1		Day 7		Day 11	
	Number	Percent	Number	Percent	Number	Percent
Lake Polander (reference)	10	100	9	90	9	90
Lake Pepin	10	100	7	70	7	70
Minnesota River	10	100	5	50	5	50

Table A8

Survival of Adult Water Flea *Daphnia magna* Exposed to Suspended Particulate Phase (SPP) of Four UMR Sediments - Experiment 1

Treatment	SPP Concentration	Replicate	Exposure Time Survival* 16 hr	40 hr	96 hr
Control	0	1	10	7	2
		2	10	10	10
		3	10	9	8
		4	10	10	5
		Mean	10	9.0	6.2
Minnesota River	50%	1	10	10	10
		2	10	10	9
		3	10	9	9
		4	10	7	5
		Mean	10	9.0	8.2
	100%	1	10	10	10
		2	10	10	10
		3	10	10	6
		4	10	10	10
		Mean	10	10	9.0
Lake Pepin	50%	1	10	10	5
		2	10	10	8
		3	10	10	10
		4	10	10	10
		Mean	10	10	8.2
	100%	1	10	9	6
		2	10	10	9
		3	10	10	9
		4	10	10	9
		Mean	10	9.7	8.2

(Continued)

* Tests were initiated with 10 organisms per replicate.

Table A8 (Concluded)

Treatment	SPP Concentration	Replicate	Exposure Time Survival* 16 hr	40 hr	96 hr
Mississippi River	50%	1	10	10	8
		2	10	10	5
		3	10	7	6
		4	10	10	8
		Mean	10	9.2	6.7
	100%	1	10	8	6
		2	10	9	6
		3	10	10	6
		4	10	10	3
		Mean	10	9.2	5.2
Lake Polander (reference)	50%	1	10	5	4
		2	10	6	3
		3	10	5	4
		4	10	8	6
		Mean	10	6.0	4.2
	100%	1	10	7	6
		2	10	6	5
		3	9	6	5
		4	10	5	4
		mean	9.7	6.0	5.0

Table A9

Number of Water Flea *Daphnia magna* Produced During Experiment 1 and Observed Alive at the 96-hr Observation Period

Treatment	SSP Concentration	Replicate 1	2	3	4	Mean
Control	0	3	3	4	11	5
Minnesota River	50%	11	1	2	6	5
	100%	13	13	5	10	10
Mississippi River	50%	6	4	0	7	4
	100%	4	2	2	3	3
Lake Pepin	50%	2	4	9	0	4
	100%	3	0	0	0	1
Lake Polander (reference)	50%	5	3	0	3	3
	100%	4	0	0	2	2

Table A10

Survival of First Instar Water Flea *Daphnia magna* Exposed to Suspended Particulate Phase (SPP) of Four UMR Sediments - Experiment 2

Treatment	SPP Concentration	Replicate	Exposure Time-Survival* 18 hr	42 hr	96 hr	144 hr**
Control A	0	1	3	3	2	2
		2	3	3	2	2
		3	5	5	4	4
		4	5	4	3	2
		5	2	2	2	2
		6	5	4	2	2
		Mean	3.8	3.5	2.5	2.3
Control B	0	1	5	5	4	--
		2	4	2	1	--
		3	5	5	4	--
		4	5	4	3	--
		5	5	5	3	--
		6	5	4	4	--
		Mean	4.8	4.1	3.2	--
Minnesota River	100%	1	5	4	4	4
		2	5	2	0	0
		3	5	5	5	5
		4	5	5	4	4
		5	5	2	3	2
		6	4	4	3	3
		Mean	4.8	3.7	3.2	3.0
Mississippi River	100%	1	4	2	2	2
		2	5	4	4	4
		3	4	4	4	4
		4	5	2	2	2
		5	4	2	2	2
		6	4	3	3	3
		Mean	4.3	2.8	2.8	2.8

(Continued)

* Tests were initiated with five organisms per replicate.
** -- indicates data not available.

Table A10 (Concluded)

Treatment	SPP Concentration	Replicate	Exposure Time-Survival 18 hr	42 hr	96 hr	144 hr
Lake Pepin	100%	1	4	3	2	1
		2	3	3	3	2
		3	2	2	2	1
		4	2	1	0	0
		5	4	3	3	3
		6	5	4	4	4
		Mean	3.3	2.7	2.5	1.8
Lake Polander (reference)	100%	1	4	4	2	2
		2	4	4	3	3
		3	4	2	0	0
		4	3	2	0	0
		5	4	3	3	3
		6	4	3	1	0
		Mean	3.8	3.0	1.5	1.3
Local VC Sediment	100%	1	3	0	0	0
		2	2	0	0	0
		3	1	1	0	0
		4	1	1	0	0
		5	1	1	1	0
		6	1	1	0	0
		Mean	1.5	0.7	0.2	0

Table A11

Survival of Fawnfoot Clam *Truncilla donaciformis* Exposed to UMR Sediments for 14 Days

Treatment	Replicate	Exposure Time-Survival Day 1	Day 14
Minnesota River	1	20	20
	2	20	20
	3	20	20
	4	20	20
	5	20	20
	6	20	20
	Mean	20	20
Lake Pepin	1	20	20
	2	20	20
	3	20	20
	4	20	20
	5	20	20
	6	20	20
	Mean	20	20
Lake Polander (reference)	1	20	20
	2	20	20
	3	20	19
	4	20	20
	5	20	20
	6	20	20
	Mean	20	19.9
Mississippi River	1	20	20
	2	20	20
	3	20	20
	4	20	18
	5	20	20
	6	20	20
	Mean	20	19.7

Table A12

Contaminant Concentrations in Tissue of Fawn-Foot Clam *Truncilla donaciformis* Exposed to Four UMR Sediments for 7 and 14 Days

Treatment	Replicate	PCB 1016 (Concentration µg/g wet wt*)	PCB 1254 (Concentration µg/g wet wt*)	PCB Total (Concentration µg/g wet wt*)	Hg (Concentration µg/g wet wt*)	Cd (Concentration µg/g dry wt*)	Pb (Concentration µg/g dry wt*)	Cu (Concentration µg/g dry wt*)	Zn (Concentration µg/g dry wt*)
Background (day 0)	1	(sample lost)							
	2	0.02	0.15	0.17					
	3	0.01	0.08	0.09					
	4	0.02	0.07	0.09					
	5	0.01	0.07	0.08					
	6	0.02	0.07	0.09					
	Mean	0.02	0.09	0.10					
Lake Pepin (day 7)	1	--	0.16	0.16					
	2	--	0.10	0.10					
	3	0.03	0.11	0.14					
	4	0.02	0.11	0.13					
	5	0.02	0.11	0.13					
	6	0.02	0.09	0.13	--				
	Mean	0.02	0.11	0.13					
Minnesota River (day 7)	1	0.02	0.07	0.09	--				
	2	0.02	0.11	0.13	--	1.779	1.026	9.22	239
	3	0.04	0.10	0.14	--	1.265	0.840	7.75	195
	4	0.02	0.05	0.07	--	1.858	1.762	10.71	272
	5	0.04	0.11	0.15					
	6	0.03	0.07	0.10	--	1.544	0.899	9.10	252
	Mean	0.03	0.09	0.11		1.612	1.132	9.20	240
Mississippi River (day 7)	1	0.02	0.01	0.03	--				
	2	0.04	0.09	0.13	--	0.923	1.168	10.06	216
	3	0.02	0.03	0.05	--				
	4	0.02	0.05	0.07	--				
	5	0.04	0.12	0.16	--	0.979	1.009	8.47	198
	6	0.02	0.07	0.09	--	0.950	0.918	8.66	169
	Mean	0.03	0.06	0.09		0.951	1.032	9.03	194
Lake Polander (reference) (day 7)	1	0.02	0.09	0.11	--	0.989	0.794	8.75	163
	2	0.02	0.10	0.12	--	1.737	0.937	8.75	232
	3	0.05	0.13	0.18	--	1.557	1.386	10.57	215
	4	0.05	0.12	0.17	--	1.380	1.231	10.68	197
	5	(sample lost)				(sample lost)			
	6	0.02	0.07	0.09	--	1.440	1.200	9.72	243
	Mean	0.03	0.10	0.13		1.421	1.110	9.69	210
Detection limit		0.01			0.05				

(Continued)

* -- indicates concentrations below detection limits. Blanks in table indicate no analysis was performed due to insufficient sample size.

Table A12 (Concluded)

Treatment	Replicate	PCB 1016 (g/g wet wt)	PCB 1254 (g/g wet wt)	PCB Total (g/g wet wt)	Hg (g/g wet wt)	Cd (g/g dry wt)	Pb (g/g dry wt)	Cu (g/g dry wt)	Zn (g/g dry wt)
Lake Pepin (day 14)	1	0.02	0.13	0.15	--	1.44	1.2	9.72	243
	2	0.01	0.04	0.05					
	3	0.02	0.09	0.11					
	4	0.03	0.09	0.12					
	5	0.01	0.06	0.07					
	6	0.04	0.15	0.19					
	Mean	0.02	0.09	0.12		1.44	1.2	9.72	243
Minnesota River (day 14)	1	0.02	0.07	0.09					
	2	--	0.01	0.01					
	3	0.01	0.02	0.03					
	4	0.01	0.03	0.04					
	5	--	0.02	0.02					
	6	0.02	0.10	0.12					
	Mean	0.02	0.04	0.05					
Mississippi River (day 14)	1	0.06	0.13	0.19					
	2	0.03	0.22	0.25					
	3	0.02	0.07	0.09					
	4	--	0.02	0.02					
	5	0.01	0.05	0.06					
	6	0.01	0.03	0.04					
	Mean	0.03	0.09	0.11					
Lake Polander (reference) (day 14)	1	0.02	0.05	0.07					
	2	--	0.07	0.07					
	3	0.02	0.04	0.06					
	4	0.01	0.04	0.05					
	5	0.01	0.05	0.06					
	6	0.04	0.07	0.11					
	Mean	0.02	0.05	0.07					
Detection limit		0.01			0.05				

Table A13

Survival of Three-Ridge Clam *Amblema plicata*

Exposed to UMR Sediments for 14 Days

Treatment	Replicate	Exposure Time-Survival Day 1	Exposure Time-Survival Day 14
Minnesota River	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18
Lake Pepin	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18
Lake Polander (reference)	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18
Mississippi River	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18

Table A14

Contaminant Concentrations in Tissue of Three-Ridge Clam *Amblema plicata* Exposed to Four UMR Sediments for 7 and 14 Days

Treatment	Replicate	PCB 1016 (µg/g wet wt*)	PCB 1254 (µg/g wet wt*)	PCB Total (µg/g wet wt*)	Hg (µg/g wet wt*)	Cd (µg/g dry wt**)	Pb (µg/g dry wt**)	Cu (µg/g dry wt**)	Zn (µg/g dry wt**)
Background (day 0)	1	--	0.08	0.08	--	1.016	0.464	7.35	185
	2	--	0.10	0.10	--	1.243	1.088	13.40	164
	3	--	0.16	0.16	--				
	4	--	0.13	0.13	--	1.080	0.682	8.23	181
	5	--	0.09	0.09	--	1.226	0.421	7.97	207
	6	--	0.11	0.11	--	1.445	0.154	5.87	199
	Mean		0.11	0.11		1.336	0.562	8.56	187
Lake Pepin (day 7)	1	--	0.10	0.10	--				
	2	--	0.06	0.06	--	1.394	0.369	8.65	211
	3	--	0.11	0.11	--	0.852	0.442	5.79	170
	4	--	0.07	0.07	--				
	5	--	0.09	0.09	--				
	6	--	0.07	0.07	--	1.146	0.541	10.28	190
	Mean		0.08	0.08		1.131	0.451	8.24	190
Minnesota River (day 7)	1	--	0.06	0.06	--				
	2	--	0.04	0.04	--	1.558	0.342	11.03	198
	3	--	0.06	0.06	--				
	4	--	0.07	0.07	--				
	5	--	0.02	0.02	--				
	6	--	0.01	0.01	--				
	Mean		0.04	0.04		1.558	0.342	11.03	198
Mississippi River (day 7)	1	--	0.03	0.03	--				
	2	--	0.07	0.07	--	0.952	1.284	11.28	189
	3	--	0.14	0.14	--	1.611	1.409	13.37	231
	4	--	0.03	0.03	--	1.184	1.602	14.42	194
	5	--	0.07	0.07	--	1.176	0.827	13.44	205
	6	--	0.03	0.03	--	1.347	0.299	14.21	183
	Mean		0.06	0.06		1.083	1.084	13.34	200
Lake Polander (day 7)	1	--	0.04	0.04	--	1.581	0.440	10.46	182
	2	--	0.05	0.05	--	1.589	0.420	22.65	230
	3	--	0.07	0.07	--	1.337	0.899	22.55	233
	4	--	0.06	0.06	--	1.337	0.572	9.61	210
	5	--	0.03	0.03	--	0.899	0.226	7.84	211
	6	--	--	--	--				
	Mean		0.05	0.05		1.349	0.511	14.62	213
Detection limit		0.01	0.01	0.01	0.05				

(Continued)

* -- indicates concentrations below detection limits.

** Blanks in table indicate no analysis was performed due to insufficient sample size.

Table A14 (Concluded)

Treatment	Replicate	Concentration µg/g wet wt PCB 1016	1254	Total	Hg	Concentration µg/g dry wt Cd	Pb	Cu	Zn
Lake Pepin (day 14)	1	--	0.04	0.04	--				
	2	0.01	0.10	0.11	--				
	3	--	0.07	0.07	--				
	4	--	0.09	0.09	--				
	5	--	0.05	0.05	--				
	6	0.01	0.05	0.06	--				
	Mean	0.01	0.07	0.07					
Minnesota River (day 14)	1	0.02	0.10	0.12	--				
	2	--	0.04	0.04	--				
	3	--	0.03	0.03					
	4	0.01	0.06	0.07	--				
	5	--	0.05	0.05	--				
	6	--	0.04	0.04	--				
	Mean	0.02	0.05	0.06					
Mississippi River (day 14)	1	--	0.04	0.04	--				
	2	--	0.05	0.05	--				
	3	--	0.05	0.05	--				
	4	--	0.07	0.07	--				
	5	--	0.03	0.03	--				
	6	--	0.04	0.04	--				
	Mean		0.05	0.05					
Lake Polander (reference) (day 14)	1	--	0.03	0.03	--				
	2	--	0.03	0.03	--				
	3	--	0.04	0.04	--				
	4	--	0.04	0.04	--				
	5	--	0.06	0.06	--				
	6	0.01	0.06	0.07	--				
	Mean	0.01	0.04	0.05					
Detection limit		0.01	0.01	0.01	0.05				

Table A15

Survival of Channel Catfish *Ictalurus punctatus* Exposed to Suspensions of UMR Sediments for 6 Days

Treatment	Replicate	Exposure Time - Survival Start	Day 6
Mississippi River	1	15	14
	2	15	15
	3	15	14
	4	15	15
	5	15	15
	Mean	15	14.6
Lake Polander (reference)	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18
Lake Pepin	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18
Minnesota River	1	18	18
	2	18	18
	3	18	18
	4	18	18
	5	18	18
	6	18	18
	Mean	18	18

Table A16

Contaminant Concentrations in Tissue of Channel Catfish *Ictalurus punctatus* Exposed to Suspensions of UMR Sediments for 6 Days

Treatment	Replicate*	Concentration µg/g wet wt** PCB 1016	PCB 1254	PCB Total	Hg	Concentration µg/g dry wt† Cd	Pb	Cu	Zn
Initial background (day 0)	1a*	--	0.01	0.01	--	0.0587	0.2730	2.35	182
	1b	--	--	--	--	0.0352	0.1700	1.68	114
	2	--	0.01	0.01	--	0.0362	0.2750	2.11	143
	3	--	0.03	0.03	--	0.0260	0.1110	1.38	104
	4	--	0.03	0.03	--	0.0267	0.1450	1.67	136
	5	--	0.02	0.02	--	0.0261	0.1800	1.75	140
	6	--	0.02	0.02	--	0.0272	0.2520	1.80	125
	Mean		0.02	0.02		0.0315	0.1973	1.79	133
Final background (day 6)	1	0.03	0.02	0.05	--				
	2	0.04	0.03	0.07	--	0.0307	0.1180	1.37	118
	3	0.04	0.02	0.06	--	0.0510	0.2000	1.19	108
	4	0.03	0.02	0.05	--	0.0184	0.0958	1.28	106
	5	--	0.03	0.03	--	0.0269	0.1110	1.18	123
	6	--	0.02	0.02	--	0.0337	0.1400	1.26	108
	Mean	0.04	0.02	0.05		0.0321	0.1330	1.26	113

(Continued)

* Notations a and b indicate sample was split and portions analyzed separately.

** Entry -- indicates concentrations below detection limits. Blanks in table indicate no analysis was performed due to insufficient sample size.

† Values for split samples were averaged and treated as the datum for that sample in calculating the mean.

(Sheet 1 of 3)

Table A16 (Continued)

		Concentration µg/g wet wt				Concentration µg/g dry wt			
		PCB							
Treatment	Replicate	1016	1254	Total	Hg	Cd	Pb	Cu	Zn
Lake Pepin	1	--	0.01	0.01	--	0.0217	0.1430	1.31	124
	2	--	0.02	0.02	--	0.0238	0.0889	1.32	121
	3	--	0.04	0.04	--	0.0395	0.2720	1.45	128
	4	--	0.01	0.01	--	0.0288	0.1570	1.41	132
	5	--	0.02	0.02	--	0.0264	0.1110	1.29	131
	6	--	0.02	0.02	--	0.0276	0.1570	1.15	158
	Mean		0.02	0.02		0.0280	0.1550	1.32	132
Minnesota River	1	--	0.02	0.02	--	0.0263	0.1630	1.14	117
	2	--	0.02	0.02	--	0.0176	0.2290	1.13	131
	3	0.02	0.02	0.04	--	0.0220	0.7760	1.70	110
	4	--	0.02	0.02	--	0.0233	0.1490	1.39	109
	5a	--	0.02	0.02	--	0.0752	0.2210	1.90	132
	5b					0.0300	0.1880	1.78	130
	6a	--	0.02	0.02	--	0.0351	0.2450	1.86	149
	6b					0.0323	0.1340	1.75	135
	Mean	0.02	0.02	0.02		0.0293	0.2850	1.50	123
Mississippi River	1	0.03	0.02	0.05	--	0.1080	0.4540	2.28	135
	2	--	0.02	0.02	--	0.0899	0.4680	0.86	133
	3	--	0.03	0.03	--	0.0950	0.5230	1.96	119
	4	0.04	0.02	0.06	--	0.0372	0.1920	1.57	128
	5	0.05	0.04	0.09	--	0.0322	0.2160	1.46	114
	Mean	0.04	0.03	0.05		0.0725	0.3710	1.63	126

(Continued)

Table A16 (Concluded)

Treatment	Replicate	Concentration µg/g wet wt PCB 1016	PCB 1254	PCB Total	Hg	Concentration µg/g dry wt Cd	Pb	Cu	Zn
Lake Polander (reference)	1	0.04	0.02	0.06	--	0.0356	0.2890	3.03	133
	2a	0.04	0.02	0.06	--	0.0659	0.3440	1.69	131
	2b					0.0410	0.2820	4.30	151
	3a	0.04	0.03	0.07	--	0.0370	0.1730	1.62	119
	3b					0.0380	0.2340	3.71	147
	4a	--	0.02	0.02	--	0.0496	0.4090	1.45	126
	4b					0.0347	0.3190	2.88	159
	5a	--	0.02	0.02	--	0.0342	0.3570	1.28	109
	5b					0.0352	0.3260	2.91	170
	6a	--	0.02	0.02	--	0.0310	0.6660	1.73	121
	6b					0.0469	0.1850	1.55	152
	Mean	0.04	0.02	0.04		0.0404	0.3230	2.43	138
Detection limit		0.01	0.01	0.01	0.05				

(Sheet 3 of 3)

Table A17

Survival of Bluegill *Lepomis macrochirus* Exposed to Suspensions of UMR Sediments for 6 Days

Treatment	Replicate	Exposure Time - Survival Start	Day 6
Mississippi River	1	14	13
	2	14	13
	3	14	14
	4	15	14
	5	14	12
	Mean	14.2	13.2
Lake Polander (reference)	1	17	17
	2	17	16
	3	17	17
	4	17	14
	5	17	16
	6	17	16
	Mean	17	16.0
Lake Pepin	1	17	15
	2	17	16
	3	17	16
	4	17	15
	5	17	17
	6	17	14
	Mean	17	15.5
Minnesota River	1	17	15
	2	17	15
	3	17	15
	4	17	15
	5	17	14
	6	17	16
	Mean	17	15

Table A18

Contaminant Concentrations in Tissue of Bluegill *Lepomis macrochirus*

Exposed to Suspensions of UMR Sediments for 6 Days

		Concentration µg/g wet wt**				Concentration µg/g dry wt†			
		PCB							
Treatment	Replicate*	1016	1254	Total	Hg	Cd	Pb	Cu	Zn
Initial background (day 0)	1a	--	0.02	0.02	--	0.0334	0.540	2.24	189
	1b					0.0176	0.188	2.15	173
	2a	--	0.02	0.02	--	0.0197	0.362	2.90	222
	2b					0.0139	0.197	6.89	211
	3a	--	0.02	0.02	--	0.0243	0.297	2.53	158
	3b					0.0197	0.262	2.21	150
	4a	--	0.02	0.02	--	0.0254	0.315	2.32	173
	4b					0.0194	0.238	2.35	149
	5a	--	0.02	0.02	--	0.0213	0.368	2.71	183
	5b					0.0171	0.215	2.39	145
	6a	--	0.02	0.02	--	0.0169	0.320	1.91	160
	6b					0.0189	0.204	2.84	130
	Mean		0.02	0.02		0.0207	0.292	2.79	170

(Continued)

* Notations a and b indicate sample was split and portions analyzed separately.

** Entry -- indicates concentrations below detection limits. Blanks in table indicate no analysis was performed due to insufficient sample size.

† Values for split samples were averaged and treated as the datum for that sample in calculating the mean.

(Sheet 1 of 3)

Table A18 (Continued)

Treatment	Replicate	Concentration µg/g wet wt PCB 1016	PCB 1254	PCB Total	Hg	Concentration µg/g dry wt Cd	Pb	Cu	Zn
Lake Pepin	1	--	0.02	0.02	--	0.0562	0.365	2.70	260
	2	--	0.03	0.03	--	0.0808	0.327	2.22	197
	3	--	0.03	0.03	--	0.0235	0.284	2.01	194
	4	--	0.02	0.02	--	0.0411	0.416	2.40	201
	5	--	--	--	--	0.0898	0.403	2.50	182
	6	--	--	--	--	0.1480	0.464	2.22	229
	Mean		0.02	0.02		0.0732	0.377	2.34	210
Minnesota River	1	--	--	--	--	0.0258	0.393	2.25	178
	2	--	--	--	--	0.0226	0.272	2.17	201
	3	--	0.01	0.01	--	0.0234	0.187	1.99	178
	4	--	0.01	0.01	--	0.0354	0.249	2.46	181
	5	--	0.02	0.02	--	0.0221	0.170	2.21	160
	6	--	0.03	0.03	--	0.0344	0.300	2.23	183
	Mean		0.02	0.02		0.0273	0.262	2.22	180
Mississippi River	1	--	0.03	0.03	--	0.0480	0.364	3.10	263
	2	--	0.03	0.03	--	0.0659	0.293	3.51	269
	3	--	0.11	0.11	--	0.0727	0.278	2.44	189
	4	--	0.03	0.03	--	0.0642	0.250	2.17	166
	5	--	0.06	0.06	--	0.0769	0.954	2.67	167
	Mean		0.05	0.05		0.0655	0.428	2.78	211

(Continued)

(Sheet 2 of 3)

Table A18 (Concluded)

		Concentration µg/g wet wt				Concentration µg/g dry wt			
		PCB							
Treatment	Replicate	1016	1254	Total	Hg	Cd	Pb	Cu	Zn
Lake Polander (reference)	1	--	0.02	0.02	--	0.0279	0.249	1.86	145
	2	--	0.04	0.04	--	0.0284	0.217	1.98	167
	3	--	0.02	0.02	--	0.0427	0.564	23.92††	159
	4	--	0.03	0.03	--	0.0542	0.206	1.62	123
	5	--	0.03	0.03	--	0.0197	0.202	1.63	149
	6	--	0.02	0.02	--	0.0151	0.178	1.10	110
	Mean		0.03	0.03		0.0313	0.269	1.64	142
Detection limit		0.01	0.01	0.01	0.05				

†† Sample contaminated; value not included in data analyses.

(Sheet 3 of 3)

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Peddicord, Richard
Biological assessment of upper Mississippi River sediments / by Richard Peddicord ... [et al]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
51, [31] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; EL-80-5)
Prepared for U. S. Army Engineer District, St. Paul, St. Paul, Minn. and Office, Chief of Engineers, U. S. Army, Washington, D. C.
References: p. 50-51.

1. Bioassay. 2. Biological communities. 3. Dredging. 4. Mississippi River. 5. Sediment. 6. Toxicity. 7. Upper Mississippi River. I. United States. Army. Corps of Engineers. St. Paul. II. United States. Army. Corps of Engineers. III. Series: Unites States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; EL-80-5.
TA7.W34m no.EL-80-5